4.1 Production Management Overview

Production management deals with how farmers combine land, water, commercial inputs, labor, and their management skills into systems and practices that produce food and fiber. To sustain production over time, farmers must make a profit and preserve their resource and financial assets. Society wants food and fiber products that are low-cost, safe to consume, and aesthetically pleasing; and production systems that preserve or even enhance the environment. These often competing goals and pressures get reflected not only in the inputs made available for production, but also in how the inputs are combined and managed at the farm level. Increasingly, farmers are facing economic and societal pressures to change from traditional or conventional systems to improved or alternative ways of managing production.

Production management encompasses various challenges that the farmer must meet to produce food and fiber:

- **Crop residue management**—deciding how much crop residue to leave on the soil surface to protect soil and conserve moisture, based on topography, soil conditions and erosion, pests, and climate.

- **Cropping management**—deciding what crops to grow and in what sequence, based on rate of return, weather, soil, government programs, pests, and available machinery.

- **Pest management**—determining pest threats to crop growth and quality and what actions to take, mindful of food and worker safety and environmental impacts.

- **Nutrient management**—determining and applying the nutrients required to foster crop yields and farm profitability, while reducing nutrient loss to the environment.

- **Irrigation water management**—determining water needed for crop growth and applying that water efficiently, considering water availability and offsite water quantity/quality impacts.

These management challenges are each examined more fully in chapters 4.2-4.6, including the types and prevalence of conventional and alternative systems and practices, and the economic and other factors affecting their use. New technology (such as precision agriculture and genetically engineered seeds) and increasing interest in organic and sustainable agriculture are affecting some farmers' production management decisions.

4.2 Crop Residue Management

Crop residue management (CRM), which calls for fewer and/or less intensive tillage operations and preserves more previous crop residue, is designed to protect soil and water resources and to provide additional environmental benefits. CRM is generally cost-effective in meeting conservation requirements and can lead to higher farm economic returns by reducing fuel, machinery, and labor costs while maintaining or increasing crop yields. Conservation tillage, the major form of CRM, was used on almost 104 million acres in 1996, over 35 percent of U.S. planted cropland area.

Contents

Crop residue management (CRM) systems include reduced tillage or conservation tillage practices such as no-till, ridge-till, and mulch-till as well as the use of cover crops and other conservation practices that provide sufficient residue cover to help protect the soil surface from the erosive effects of wind and water (see box, "Crop Residue Management and Tillage Definitions," p. 156).

Why Manage Crop Residue?

Historically, crop residues were removed from farm fields for livestock bedding, feed, and/or other off-field purposes. Whatever residues remained on the fields after harvest were burned off primarily to control pests, plowed under, or tilled into the soil. Culturally, some farmers take pride in having their fields "clean" of residue and intensively tilled to obtain a smooth surface in preparation for planting. More recently, farmers have adopted CRM practices—with government encouragement—because of new knowledge about the benefits of leaving greater residue and the availability of appropriate technology. CRM can benefit society through an improved environment, and farmers through enhanced farm economic returns. However, adoption of CRM may not lead to clear environmental benefits in all regions and, similarly, may not be economically profitable on all farms. Some questions remain. Public and private interests are continuing cooperative efforts to address the barriers to realizing greater benefits from CRM practices. For example, recent advances in planting equipment permit seeding new crops through heavier surface residue into untilled soil and even directly into killed sod. Long-term effects of CRM can include:

Reduced Erosion. Tillage systems that leave substantial amounts of crop residue evenly distributed over the soil surface reduce wind erosion and the kinetic energy impact of rainfall, increase water infiltration and moisture retention, and reduce surface sediment and water runoff (Edwards, 1995). Several field studies (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall and others, 1984; Sander and others, 1989) conducted on small watersheds under

Crop Residue Management and Tillage Definitions

Little or no management of residue	Crop Residue Management (CRM)			
Conventional tillage	**Reduced tillage**	**Conservation tillage**		
		Mulch-till	**Ridge-till**	**No-Till**
Moldboard plow or intensive tillage used	No use of moldboard plow and intensity of tillage reduced	Further decrease in tillage (see below)	Only ridges are tilled (see below)	No tillage performed (see below)
< 15% residue cover remaining	15-30% residue cover remaining	-----30% or greater residue cover remaining-----		

Crop Residue Management (CRM) is a year-round conservation system that usually involves a reduction in the number of passes over the field with tillage implements and/or in the intensity of tillage operations, including the elimination of plowing (inversion of the surface layer of soil). CRM begins with the selection of crops that produce sufficient quantities of residue to reduce wind and water erosion and may include the use of cover crops after low residue-producing crops. CRM includes all field operations that affect residue amounts, orientation, and distribution throughout the period requiring protection. Site specific residue cover amounts needed are usually expressed in percentage but may also be in pounds. Tillage systems included under CRM are conservation tillage (no-till, ridge-till, and mulch-till) and reduced tillage.

Conservation Tillage—Any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. Two key factors influencing crop residue are 1) the type of crop, which establishes the initial residue amount and its fragility, and 2) the type of tillage operations prior to and including planting.

Conservation Tillage Systems include:

No-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

Mulch-till—The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with herbicides and/or cultivation.

Reduced Tillage (15-30% residue)—Tillage types that leave 15-30 percent residue cover after planting, or 500-1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Weed control is accomplished with herbicides and/or cultivation.

Conventional Tillage (less than 15% residue)—Tillage types that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Generally includes plowing or other intensive tillage. Weed control is accomplished with herbicides and/or cultivation.

Conventional Tillage Systems (as defined in the Cropping Practices Survey):

Conventional tillage with moldboard plow—Any tillage system that includes the use of a moldboard plow.

Conventional tillage without moldboard plow—Any tillage system that has less than 30 percent remaining residue cover and does not use a moldboard plow.

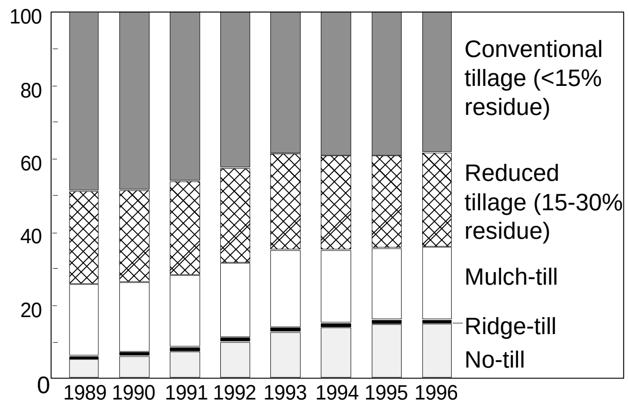
Source: USDA, ERS, based on Bull, 1993, and Conservation Tillage Iinformation Center, 1996.

natural rainfall on highly erodible land (14 percent slope) have compared erosion rates among tillage systems. Compared with the moldboard plow, no-till reduces soil erosion by as much as 90 percent and mulch-till and ridge-till by up to 70 percent.

Cleaner Surface Runoff. Surface residues help intercept nutrients and chemicals and hold them in place until they are used by the crop or degrade into harmless components (Dick and Daniel, 1987; Helling, 1987; Wagenet, 1987). In addition, the filtering action of increased organic matter in the top layer of soil results in cleaner runoff (by reducing contaminants such as sediment and adsorbed or dissolved chemicals), and thus benefits water quality in lakes and streams (Onstad and Voorhees, 1987; Conservation Technology Information Center or CTIC, 1996). Studies under field conditions indicate that while the quantity of water runoff from no-till fields was variable depending on the frequency and intensity of rainfall, clean-tilled soil surfaces produce substantially more runoff (Edwards, 1995). Runoff from no-till and mulch-till fields averaged about 30 and 40 percent of the amounts from moldboard-plowed fields (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall and others, 1984; Sander and others, 1989). Average herbicide runoff losses from treated fields with no-till and mulch-till systems for all products and all years were about 30 percent of the runoff levels from moldboard-plowed fields (Fawcett and others, 1994). Under normal production conditions, the presence of increased crop residue reduces the volume of contaminants associated with runoff to surface waters by constraining sediment losses and enhancing infiltration (Edwards, 1995; Fawcett, 1987).

Higher Soil Moisture and Water Infiltration. Crop residues on the soil surface slow water runoff by acting as tiny dams, reduce surface crust formation, and enhance infiltration (Edwards, 1995). The channels (macropores) created by earthworms and old plant roots, when left intact with no-till, improve infiltration to help reduce or eliminate field runoff. This raises the prospect of increased water infiltration carrying agricultural chemicals into the groundwater in specific situations (more discussion later of groundwater effects). Combined with reduced water evaporation from the top few inches of soil and with improved soil characteristics, the higher level of soil moisture can contribute to higher crop yields in many cropping and climatic situations (CTIC, 1996). However, in some areas, soil moisture levels can also be too high for optimal crop growth or leave soils too cool and wet at planting time, thereby reducing yields.

Figure 4.2.1--National use of crop residue management, 1989-96



Source: USDA, ERS, based on Conservation Technology Information Center data.

Possible Higher Economic Returns. CRM may result in higher economic returns from increased or stable crop yields and lower input costs. CRM systems usually involve fewer trips over a field, resulting in reduced fuel and labor requirements and lower machinery operating costs. Whether CRM in fact reduces total costs of production for farmers depends on the magnitude of the cost savings from reduced tillage operations relative to the other possible costs affected by CRM practices. For example, there may be increased costs associated with the need for specialized equipment to handle high residue on the soil surface, and increased management, labor, and materials to effectively control pest infestations. Moreover, whether CRM results in higher net returns from farming depends on the effects of CRM practices on yields as well as costs. Farmers continually face tradeoffs between advantages and limitations in choosing the tillage system most appropriate for their conditions.

Improved Long-Term Soil Productivity. Less intensive tillage reduces the breakdown of crop residues and the loss of soil organic matter. The less a soil is tilled, the more carbon is sequestered in the soil to build organic matter and maintain long-term productivity. No-till improves soil structure (tilth) by increasing soil particle aggregation (small soil clumps), which facilitates water movement through the soil and enables plants to expend less energy to establish roots. No-till can also help to minimize soil compaction through fewer trips over the field and reduced weight and horsepower requirements (CTIC, 1996).

Table 4.2.1—National use of crop residue management practices, 1989-96[1]

Item	1989	1990	1991	1992	1993	1994	1995	1996
				Million acres				
Total area planted[2]	279.6	280.9	281.2	282.9	278.1	283.9	278.7	290.2
Area planted with:								
No-till	14.1	16.9	20.6	28.1	34.8	39.0	40.9	42.9
Ridge-till	2.7	3.0	3.2	3.4	3.5	3.6	3.4	3.4
Mulch-till	54.9	53.3	55.3	57.3	58.9	56.8	54.6	57.5
Total conservation tillage	71.7	73.2	79.1	88.7	97.1	99.3	98.9	103.8
Other tillage types:								
Reduced tillage (15-30% residue)	70.6	71.0	72.3	73.4	73.2	73.1	70.1	74.8
Conv. tillage (< 15% residue)	137.3	136.7	129.8	120.8	107.9	111.4	109.7	111.6
Total other tillage types	207.9	207.7	202.1	194.2	181.0	184.6	179.7	186.4
Percentage of area with:				*Percent*				
No-till	5.1	6.0	7.3	9.9	12.5	13.7	14.7	14.8
Ridge-till	1.0	1.1	1.1	1.2	1.2	1.3	1.2	1.2
Mulch-till	19.6	19.0	19.7	20.2	21.2	20.0	19.6	19.8
Total conservation tillage	25.6	26.1	28.1	31.4	34.9	35.0	35.5	35.8
Other tillage types:								
Reduced tillage (15-30% residue)	25.3	25.3	25.7	25.9	26.3	25.8	25.2	25.8
Conv. tillage (< 15% residue)	49.1	48.7	46.1	42.7	38.8	39.3	39.3	38.4
Total other tillage types	74.4	73.9	71.9	68.6	65.1	65.0	64.5	64.2

[1] For tillage system definitions, see box "Crop Residue Management and Tillage Definitions," p. 156.

[2] Total area planted does not include newly established permanent pastures, fallow, annual conservation use, and Conservation Reserve Program (CRP) acres. However, it does include newly seeded alfalfa and other rotational forage crops in the year they are planted.

Source: USDA, ERS, based on Conservation Technology Information Center (CTIC) data from Crop Residue Management Surveys.

Reduced Release of Carbon Gases and Air Pollution. Intensive tillage contributes to the conversion of soil carbon to carbon dioxide, which in the atmosphere can combine with other gases to affect global warming. Increased crop residue and reduced tillage enhance the level of naturally occurring carbon in the soil and contribute to lower carbon dioxide emissions. In addition, CRM requires fewer trips across the field and less horsepower, which reduces fossil fuel emissions. Crop residues reduce wind erosion and the generation of dust-caused air pollution (CTIC, 1996).

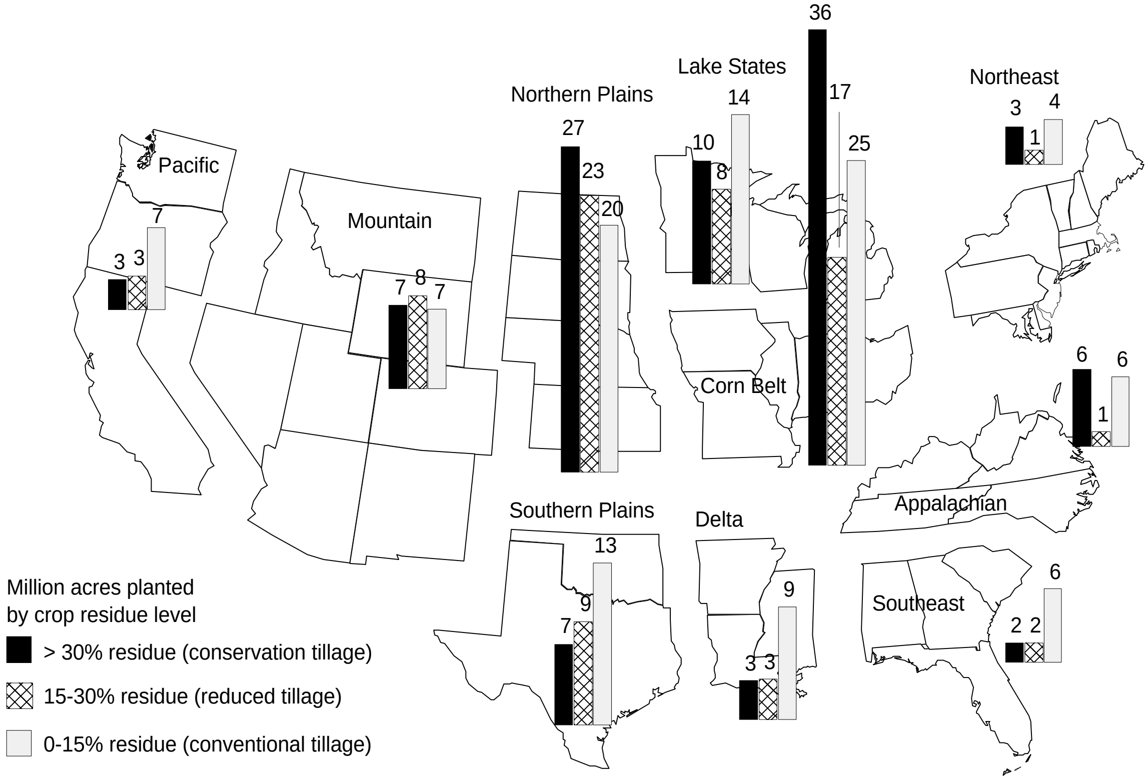
National and Regional CRM Use

In 1996, U.S. farmers practiced conservation tillage on almost 104 million acres, up from 72 million acres in 1989 (table 4.2.1). Conservation tillage now accounts for more than 35 percent of U.S. planted crop acreage (fig. 4.2.1). Most of the growth in conservation tillage since 1989 has come from expanded adoption of no-till, which can leave as much as 70 percent or more of the soil surface covered with crop residues. Use of no-till practices increased as farmers implemented conservation compliance plans from 1990 to 1995 as required under the Food Security Act and subsequent farm legislation.

The Corn Belt and Northern Plains, with 51 percent of the Nation's planted cropland, accounted for three-fifths of total conservation tillage acres in 1996 (fig. 4.2.2). These regions, plus the Lake States, Mountain region, and Southern Plains, have substantial acreage with 15-30 percent residue cover which, with improved crop residue management, has the potential to qualify as conservation tillage (which requires 30 percent or more surface residue cover).

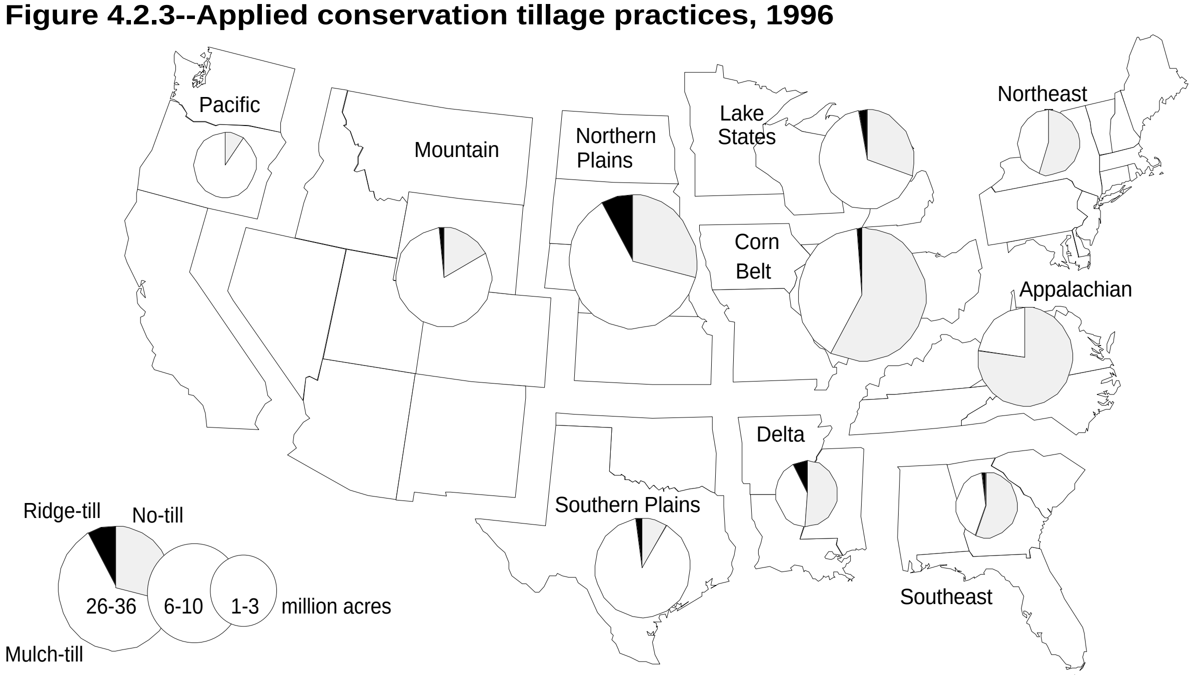
U.S. crop area planted with no-till tripled to almost 43 million acres between 1989 and 1996, while the area planted with clean tillage systems (less than 15 percent residue cover) declined by about one-fifth. Since 1989, no-till's share of conservation tillage acreage has increased while the share with mulch-till and ridge-till has remained fairly stable (fig. 4.2.1). No-till's share of conservation tilled area is greater in the six eastern regions than elsewhere (fig. 4.2.3). The aftereffects of the 1993 Midwest floods resulted in a slight decline during 1994 in acres planted (percent) with conservation tillage, mostly in mulch tillage, in the Corn Belt and Lake States (fig. 4.2.4).

Figure 4.2.2--Crop residue levels on planted acreage by region, 1996



Source: USDA, ERS, based on Conservation Technology Information Center data.

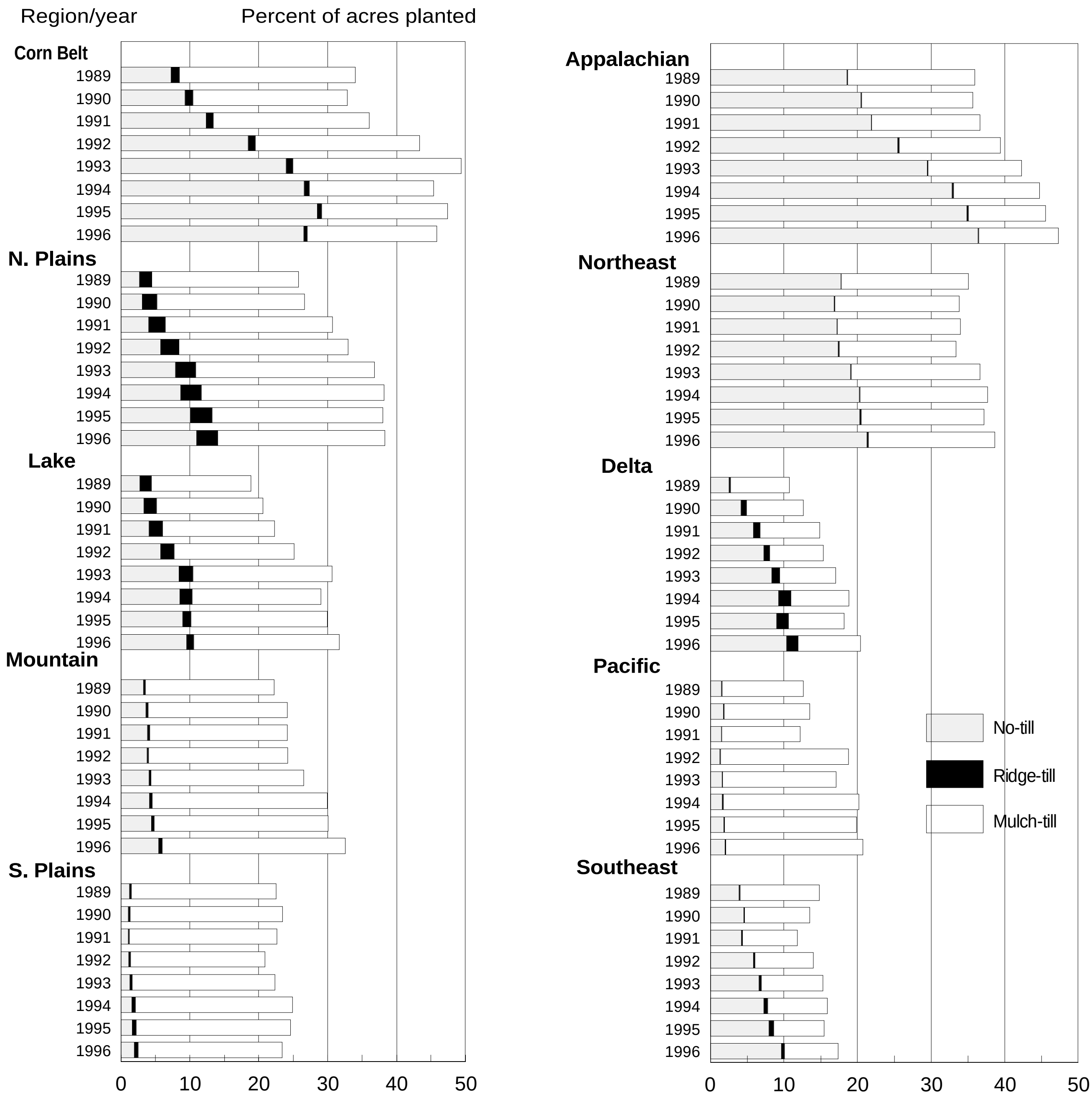
Figure 4.2.3--Applied conservation tillage practices, 1996



Circle size represents conservation tillage area in million acres (range in ascending size).

Source: USDA, ERS, based on Conservation Technology Information Center data.

Figure 4.2.4--Conservation tillage use by region, 1989-96



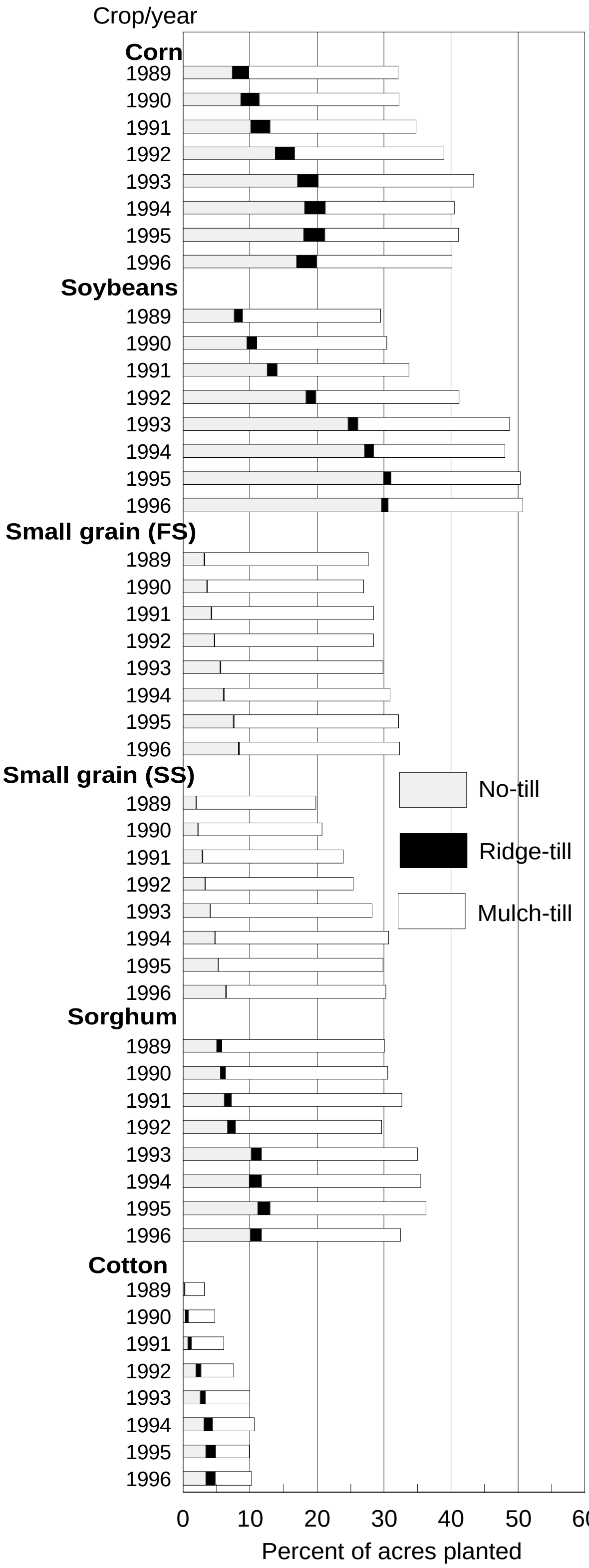
Source: USDA, ERS, based on Conservation Technology Information Center data.

Over 1989-96, the share of acres planted with no-till showed an increase for most years in nearly all regions (fig. 4.2.4).

CRM Use on Major Crops

Conservation tillage was used mainly on corn, soybeans, and small grains in 1996. Over 45 percent of the total acreage planted to corn and soybeans was conservation-tilled. Expanded use of no-till has been greater for row crops (that is, corn and soybeans) than for small grains or sorghum (fig. 4.2.5). Fields planted to row crops tend to be more susceptible to erosion because these crops provide less vegetative cover, especially earlier in the growing season. On double-cropped fields, conservation tillage was used on more than two-thirds of soybean acreage, more than half of corn acreage, and about half of sorghum acreage. The use of no-till with double-cropping

Figure 4.2.5--Conservation tillage use by major crop, 1989-96



FS = Fall seeded SS = Spring seeded

Source: USDA, ERS, based on Conservation Technology Information Center data.

facilitates getting the second crop planted quickly and limits potential moisture losses from the germination zone in the seedbed, allowing greater flexibility in cropping sequence or rotation (Sandretto and Bull, 1996).

The 1988-95 Cropping Practices Surveys (CPS) provide detailed data on residue levels and tillage systems for individual field crops in major producing States (for more discussion, see "Cropping Practices Survey" in the appendix). The advantages of the CPS for analysis of CRM is that it allows the linking of CRM practices to other relevant details about the farm production system, such as the type of tillage equipment used and the number of trips made over a field. These annual surveys indicate a decline in the use of the moldboard plow and other conventional tillage systems and an increase in the use of all types of conservation tillage for most of the major field crops. Less than 10 percent of the surveyed area in major producing States used a moldboard plow in 1995, down from 20 percent in 1988.

Corn. Tillage systems used for corn production in the 10 major producing States indicate a trend toward the use of conservation tillage systems (table 4.2.2). No-till systems were used on 17 percent of the acreage in 1995, up from only 5 percent in 1989, and exceeded 20 percent in several Corn Belt States. Ridge-till systems increased to 3 percent of the total acreage, but this expansion was mainly confined to Nebraska and Minnesota. A moldboard plow was used on 8 percent of 1995 corn acres, down from 20 percent in 1988.

Soybeans. Soybean production also indicated a trend toward greater use of conservation tillage systems. The 14 major soybean producing States were divided into northern and southern areas. The northern area showed a steady increase in no-till system use from 3 percent of the acreage in 1988 to 30 percent in 1995. At the same time, mulch-till increased from 14 to 24 percent and use of the moldboard plow dropped from 28 to 8 percent. The small share of soybean acreage with ridge-till was located mainly in Nebraska and Minnesota, where some soybeans are grown in rotation with ridge-till corn. The southern area increased no-till system use from 7 percent of the acreage in 1988 to 25 percent in 1995.

Cotton. Nearly all cotton was produced using conventional tillage methods in the six major cotton States. However, use of the moldboard plow decreased to less than one-half of the 1988 level. Arizona, California, and parts of Texas have State

Table 4.2.2—Tillage systems used in field crop production in major producing States, 1988-95[1]

Item	Unit	1988	1989	1990	1991	1992	1993	1994	1995
Corn (10 States)	*1,000 acres*[2]	53,200	57,900	58,800	60,350	62,850	57,350	62,500	55,850
Residue remaining after planting	*Percent*	19	19	22	24	27	29	30	29
Conventional tillage	*Percent of acres*	80	78	74	70	61	58	57	59
With moldboard plow		20	19	17	15	12	9	8	8
Without moldboard plow		60	59	57	55	49	49	49	51
Conservation tillage		21	22	27	30	39	42	43	41
Mulch-till		14	17	18	20	25	24	23	21
Ridge-till		*	*	*	*	2	3	3	3
No-till		7	5	9	10	12	15	17	17
Northern soybeans (7 States)	*1,000 acres*[2]	36,550	37,750	36,400	38,850	38,150	42,500[3]	43,750[4]	41,700
Residue remaining after planting	*Percent*	17	19	19	25	28	35	36	38
Conventional tillage	*Percent of acres*	83	77	74	66	59	52	47	45
With moldboard plow		28	26	23	18	12	8	9	8
Without moldboard plow		55	51	51	48	47	44	38	37
Conservation tillage		17	22	27	35	41	48	53	54
Mulch-till		14	18	21	25	26	25	26	24
Ridge-till		*	*	*	*	1	1	1	1
No-till		3	4	6	10	14	22	26	30
Southern soybeans (7 States)	*1,000 acres*[2]	12,200	13,380	11,850	10,800	10,480	NA[4]	NA[4]	10,140
Residue remaining after planting	*Percent*	14	15	19	17	18	NA	NA	27
Conventional tillage	*Percent of acres*	88	87	81	83	79	NA	NA	68
With moldboard plow		3	4	4	3	3	NA	NA	1
Without moldboard plow		85	82	78	80	76	NA	NA	67
Conservation tillage		12	15	19	17	24	NA	NA	32
Mulch-till		5	5	7	6	8	NA	NA	7
Ridge-till		*	*	*	*	id	NA	NA	nr
No-till		7	10	12	11	14	NA	NA	25
Upland cotton (6 States)	*1,000 acres*[2]	9,700	8,444	9,730	10,860	10,200	10,360	10,023	11,650
Residue remaining after planting	*Percent*	2	2	3	3	3	2	3	3
Conventional tillage	*Percent of acres*	100	99	98	97	100	99	99	98
With moldboard plow		28	15	14	21	12	16	10	13
Without moldboard plow		72	84	84	76	88	83	89	85
Conservation tillage		id	id	2	2	id	1	1	2
Mulch-till		id	id	1	1	id	**	**	**
No-till		id	id	1	1	id	1	1	1
Winter wheat (12-15 States)[5]	*1,000 acres*[2]	32,830	34,710	40,200	34,180	36,990	37,210	34,590	34,265
Residue remaining after planting	*Percent*	17	17	18	17	19	18	18	20
Conventional tillage	*Percent of acres*	82	84	81	84	79	80	83	78
With moldboard plow		15	16	12	12	11	6	8	11
Without moldboard plow		67	68	69	72	68	76	75	67
Conservation tillage		17	16	20	16	21	18	17	22
Mulch-till		16	15	17	13	18	14	12	15
No-till		1	1	3	3	3	4	5	7
Spring and durum wheat (4-5 States)[6]	*1,000 acres*[2]	12,280	19,580	18,900	16,500	19,550	18,900	19,700	18,700
Residue remaining after planting	*Percent*	18	22	22	24	23	25	25	22
Conventional tillage	*Percent of acres*	77	68	73	66	68	65	64	73
With moldboard plow		14	8	10	7	8	8	7	6
Without moldboard plow		63	60	63	59	60	57	57	67
Conservation tillage		23	32	27	34	32	35	36	29
Mulch-till		22	31	25	31	26	28	30	22
No-till		1	1	2	3	6	7	6	5
Total acres surveyed	*1,000 acres*[2]	156,760	171,764	175,880	171,040	178,220	166,320	170,563	172,305
Conventional tillage	*Percent of acres*	82	79	77	74	69	65	63	64
With moldboard plow		19	17	15	14	11	8	8	8
Without moldboard plow		63	62	62	60	58	57	55	56
Conservation tillage		18	21	23	26	31	35	37	36
Mulch-till		13	17	17	19	21	21	21	19
Ridge-till		*	*	*	*	1	1	1	1
No-till		5	4	6	7	9	13	15	16

id = Insufficient data. * = Included in no-till for these years. ** = Less than 1 percent. NA = Not available.[1] For the States included, see "Cropping Practices Survey" in the appendix. For tillage system definitions, see box "Crop Residue Management and Tillage Definitions." [2] Preliminary. Planted acres except for winter wheat (harvested). [3] May not add due to rounding. [4] Arkansas in 1993 and 1994 is included in Northern area. Previously, Arkansas was included with GA, KY, LA, MS, NC, and TN (all not surveyed in 1993 and 1994) to comprise Southern area. [5] Winter wheat includes 15 States in 1988-89 and 1991-92; 12 States in 1990; and 13 States in 1993-95. [6] Spring wheat includes 5 States in 1988-89 and 4 States in 1990-95. Durum wheat includes only ND. Source: USDA, ERS, Cropping Practices Survey data.

"plow-down" laws requiring that the cotton plant be disposed of to eliminate the over-winter food source for bollworms and boll weevils. Some producers have misinterpreted these laws to mean that the previous crop must be plowed under with a moldboard plow. California producers mainly use multiple passes with a heavy disk. In some areas of Texas, the moldboard plow is also used to bring up clay subsoil in order to cover the soil surface with clods to help control wind erosion. The large number of tillage trips across the field (averaging 6.1) leaves very little residue, even without use of the moldboard plow. Research is being conducted in a number of cotton producing States on the use of strip-till and no-till systems and the "stale seedbed" system, which uses cover crops or weeds to provide vegetative cover on the field from harvest to the next planting season.

Winter Wheat. Except for 1994 and 1995, a steady decline in moldboard plow use occurred in winter wheat production since 1988 (table 4.2.2). Meanwhile, no-till and conventional tillage without the plow showed a corresponding increase. The heavy rains and flooding in some States during 1993 affected planting of the 1994 crop. Siltation from flooding and the impact from heavy rains may have contributed to increased use of the moldboard plow in 1994 and 1995 (Bull and Sandretto, 1996).

Spring and Durum Wheat. Variations in the type of tillage system used in the production of spring and durum wheat may be partly due to weather-soil relationships in the areas producing these crops. Much of the wheat produced in the Great Plains and the Western States is grown after a fallow period. Implement passes made during the fallow year are included in determining residue levels, hours per acre, and trips over the field. Normal fallow procedure in these regions starts with chisel plowing and other noninversion tillage operations in the fall instead of a pass with a moldboard plow. For these regions, therefore, more trips over the field occur under conventional tillage without the moldboard plow than for tillage with the moldboard plow.

Factors Affecting CRM Adoption

The trend toward adoption of conservation tillage and a corresponding decline in clean tillage has been stimulated by the prospect of higher economic returns with conservation tillage and by public policies and programs promoting conservation tillage for its conservation benefits. The major limitations to adoption of soil-conserving tillage systems for some farmers include additional management skill requirements, expectations of lower crop yields and/or economic returns in specific geographic areas or situations, negative attitudes or perceptions, and institutional constraints.

Prospects for Higher Economic Returns

Higher economic returns with CRM result primarily from some combination of increased or stable crop yields and an overall reduction in input costs, with both heavily dependent on characteristics of the resource base and appropriate management (Clark and others, 1994).

Yield Response. Yield response with soil-conserving tillage systems varies with location, site-specific soil characteristics, climate, cropping patterns, and level of management skills. In general, long-term field trials on well-drained to moderately well-drained soils or on sloping land show slightly higher no-till yields, particularly with crop rotations, compared with conventional tillage (Hudson and Bradley, 1995; CTIC, 1996). Experienced no-till farmers claim greater yields from increased infiltration and improved soil properties such as reduced erosion and soil compaction, increased soil organic matter and earthworm activity, and improved soil structure (tilth) in 4-7 years from when the system becomes established (CTIC, 1996). A mulch-till system may be more appropriate where soil varies greatly within a field, where pre-plant incorporated herbicides are used for weed control, or where equipment or management limitations preclude the use of no-till or ridge-till (CTIC, 1996).

The benefits from improved moisture retention in the root zone—that derive from reduced water runoff, increased infiltration, and suppressed evaporation from the soil surface—usually increase crop yields, especially under dry conditions. In some areas of the northern Great Plains, these benefits permit a change in the cropping pattern to reduce the frequency of moisture-conserving fallow periods (Clark and others, 1994).

Increased crop residue on the soil surface tends to keep soils cooler, wetter, and less aerated (Mengel and others, 1992). These characteristics under cool, wet planting conditions, especially in some Northern States, have been blamed for delayed plantings, uneven stands, and lower corn yields (Griffith and others, 1988). However, with hot, dry weather later in the growing season, the effects of increased organic matter, improved moisture retention and permeability, and reduced nutrient losses from erosion all benefit crop yields. No-till is particularly well suited for double-cropping because farmers can plant

Table 4.2.3—Pesticide use on corn by tillage system, 10 major producing States, 1994[1]

Item	Conventional tillage: with moldboard plow	Conventional tillage: without moldboard plow	Mulch tillage	No tillage	Ridge tillage
	Treated acres as a percent of total planted				
Herbicides					
Any herbicide	93.4	98.0	98.6	99.2	99.0
(Avg. lbs./treated acre)	(2.2)	(2.8)	(2.7)	(3.3)	(2.0)
Major active ingredients:					
Atrazine	52.3	66.5	66.6	84.0	78.1
Cyanazine	19.5	18.4	18.5	35.0	10.5
Acetochlor	2.2	7.6	8.3	4.4	6.2
Alachlor	18.0	17.2	16.4	18.1	21.3
Metolachlor	24.1	32.9	35.4	28.4	42.3
Nicosulfuron	18.1	12.5	14.7	10.4	7.9
Pendimethalin	5.2	2.6	2.1	1.7	*
2,4-D	8.9	11.2	11.6	25.8	15.3
Dicamba	29.0	28.7	36.0	20.6	22.4
Glyphosate	1.3	0.9	1.7	18.7	4.4
Bromoxynil	8.5	9.9	11.7	6.0	10.9
Insecticides					
Any insecticide	24.2	23.9	26.9	26.6	51.9
(Avg. lbs./treated acre)	(1.0)	(0.8)	(0.8)	(0.7)	(0.9)
Major active ingredients:					
Chlorpyrifos	10.2	7.5	7.7	6.7	6.0
Fonofos	3.9	2.3	1.9	1.2	9.6
Methyl parathion	*	1.8	1.8	2.7	20.6
Terbufos	4.7	6.1	7.6	6.2	10.2
Permethrin	*	2.7	2.3	6.7	6.8
Tefluthrin	*	3.4	4.4	3.9	5.8
Fungicides	nr	nr	nr	nr	nr

[1] For States included, see "Cropping Practices Survey" in the appendix.
nr = none reported. * = insufficient sample size.
Source: USDA, ERS, 1994 Cropping Practices Survey data.

the second crop quickly, minimizing moisture loss from the germination zone (Sandretto and Bull, 1996).

The crop grown in the previous year can have a great influence on the success of conservation tillage systems, especially no-till. The kind, amount, and distribution of previous crop residue can influence soil temperature, seed germination, and early growth. Lower seed germination and lack of early growth sometimes result from an allelopathic (negative) effect due to placing seed under or near decaying residue from the same crop or a closely related species (Griffith and others, 1992; CTIC, 1996). No-till, mulch-till, and even conventional tillage systems are more likely to be successful with crop rotation than with monoculture. Ridge-till is best suited to row crops, and therefore is often used with monoculture. However, monoculture often results in lower yields and generally requires greater fertilizer and pesticide use compared with crop rotations, regardless of tillage system (Bull and Sandretto, 1995).

Crop yields can be significantly affected by pest populations, which frequently change under different tillage systems. Maintaining or increasing yields when changing tillage systems requires skillful use of the various means of pest control, including pesticide application, cultivation, cover crops, crop rotation, scouting, and other integrated pest management practices (see box, "Weed Control and Tillage," p. 168, for more detail).

Changes in Pesticide Use. Pesticide use on major crops differs among tillage systems, but it is difficult to distinguish the effects related to tillage systems

Table 4.2.4—Pesticide use on soybeans by tillage system, 8 major producing States, 1994[1]

Item	Conventional tillage		Mulch tillage	No tillage	Ridge tillage
	with moldboard plow	without moldboard plow			
	Treated acres as a percent of total planted				
Herbicides					
Any herbicide	97.9	98.1	99.4	98.0	94.1
(Avg. lbs./treated acre)	(1.0)	(1.1)	(1.1)	(1.3)	(0.9)
Major active ingredients:					
Alachlor	6.9	7.0	6.1	6.8	31.4
Metolachlor	8.2	8.1	6.8	9.3	10.1
2,4-D	0.5	1.2	3.9	35.4	25.3
Acifluorfen	4.4	12.1	8.7	8.0	nr
Fenoxaprop-ethyl	5.5	4.8	3.3	6.1	5.1
Fluazifop-P-butyl	7.7	7.4	6.9	9.9	5.1
Quizalofop-ethyl	5.2	5.6	6.2	8.6	nr
Chlorimuron-ethyl	13.6	14.4	13.0	20.1	5.1
Thifensulfuron	16.0	11.1	15.2	15.9	10.1
Imazaquin	9.0	22.0	14.2	16.7	nr
Imazethapyr	47.9	36.2	49.9	41.6	54.6
Pendimethalin	14.0	24.9	26.1	26.6	nr
Trifluralin	31.5	31.5	29.1	1.5	nr
Metribuzin	11.0	11.1	6.1	13.2	10.1
Glyhposate	1.2	1.5	4.6	54.5	40.5
Bentazon	16.0	14.0	15.4	12.6	nr
Lactofen	6.5	2.9	4.7	5.0	12.1
Sethoxydim	2.3	5.2	7.6	9.3	8.2
Insecticides	*less than 1 percent overall*				
Fungicides	*less than 1 percent overall*				

[1] For States included, see "Cropping Practices Survey" in the appendix.
nr = none reported. * = insufficient sample size.
Source: USDA, ERS, 1994 Cropping Practices Survey data.

from differences in pest populations between areas and from one year to the next, and from use of other pest control practices. Factors other than tillage that affect pest populations may have greater impact on pesticide use than type of tillage (Bull and others, 1993). The 1994 CPS data for major field crops also illustrate that differences among tillage systems tend to be more in the combinations of active ingredients applied than in the proportion of acres treated or the amount applied per treated acre.

In 1994, nearly all **corn** acres under all tillage systems were treated with herbicides (table 4.2.3). The overall application rate (pounds per acre treated) was highest for no-till and lowest for ridge-till. Differences between tillage systems were shown to be greater among the active ingredients applied than in the overall average amount applied per treated acre. Of the 11 most commonly used herbicides on corn, 2 were applied most frequently with conventional-till, 3 with mulch-till, 4 with no-till, and 2 with ridge-till. A comparison between no-tilled and conventionally tilled corn acreage shows that 6 of the 11 most commonly used herbicides were more frequently used with conventional-till and 5 were more frequently used with no-till.

The share of corn acreage treated with insecticides was slightly over one-half of ridge-tilled acres, but only about one-fourth with other tillage systems (table 4.2.3). No-till acres received slightly less insecticide per treated acre than did acreage with other tillage systems. No fungicide use was reported on surveyed corn acreage.

Most **soybean** acres under all tillage systems were treated with herbicides, but few or none were treated with insecticides or fungicides. A greater variety of herbicides were used on soybeans than on corn or wheat (table 4.2.4). Differences in the specific herbicide active ingredients applied existed between tillage systems, but the overall average amounts applied per treated acre were similar, although slightly higher for no-till. Of the 18 most commonly applied herbicides on soybeans, 5 were applied most frequently with conventional-till, 9 with no-till, and 4 with ridge-till.

A much smaller share of **winter wheat** acreage than corn or soybeans was treated with herbicides, ranging from 39 percent of no-till acreage to 51 percent of conventionally tilled acreage (table 4.2.5).

Survey results for recent years indicate lower rates of insecticide use with no-till than with other tillage systems, partly because no-till systems are often used in combination with crop rotations. Greater and more frequent insecticide use was reported for moldboard plowing and ridge-till, respectively, both of which are characterized by continuous production of a single crop. No-till corn and soybeans received slightly higher applications of herbicides than did other tillage systems, but the additional pesticide costs are usually more than offset by substantial cost savings from reduced field operations (CTIC, 1996). Employing integrated pest management practices such as scouting to limit spraying to isolated problem areas can reduce costs and the amount of pesticide used, regardless of tillage system (Sandretto and Bull, 1996).

Table 4.2.5—Pesticide use on winter wheat by tillage system, 13 major producing States, 1994[1]

Item	Coventional tillage		Mulch tillage	No tillage
	with mldbd. plow	w/out mldbd. plow		
	Treated acres as a percent of total planted			
Herbicides				
Any herbicide	49.4	50.6	43.1	38.7
(Avg. lbs./treated acre)	(0.45)	(0.35)	(0.38)	(0.43)
Major active ingredients:				
2,4-D	14.4	24.4	28.9	14.2
MCPA	7.7	4.9	3.0	8.5
Chlorsulfuron	25.5	15.1	4.5	nr
Metsulfuron-methyl	7.9	13.7	17.9	nr
Thifensulfuron	5.8	4.2	3.3	13.3
Tribenuron-methyl	6.1	4.2	4.2	14.2
Triasulfuron	5.3	5.6	3.6	*
Dicamba	5.1	10.3	8.7	*
Insecticides	*less than 1 percent overall*			
Fungicides	*less than 1 percent overall*			

[1] For States included, see "Cropping Practices Survey" in the appendix.
nr = none reported. * = insufficient sample size.
Source: USDA, ERS, 1994 Cropping Practices Survey data.

Impacts on Production Costs. Choice of tillage system affects machinery, chemical, fuel, and labor costs. In general, decreasing the intensity of tillage or reducing the number of operations results in lower machinery, fuel, and labor costs. These cost savings may be offset somewhat by potential increases in chemical costs depending on the herbicides selected for weed control and the fertilizers required to attain optimal yields (Siemens and Doster, 1992). The cost of pesticides with alternative tillage systems is not simply related to the total quantity of all pesticides used. Alternative pesticides (active ingredients) and/or different quantities of the same or similar pesticides are often used with different tillage systems. Newer pesticides are often used at a much lower rate but are quite often more expensive. This complicates the prediction of cost relationships between tillage systems. When making comparisons among tillage systems, the cost calculation must be based on the specific quantity and price of each pesticide used (Bull and others, 1993).

The reduction in labor requirements per acre for higher residue tillage systems can be significant and can result in immediate cost savings. Less hired labor results in direct savings, while less operator or family labor leaves more time to generate additional income by expanding farm operations or working at off-farm jobs. However, the benefits from tillage systems that reduce labor and time requirements may be greater than perceived from just the cost savings per acre. Consideration must be given to the opportunity cost of the labor and time saved. Farmers who spend less time in the field have more time for financial management, improved marketing, or other activities to improve farm profitability (Sandretto and Bull, 1996).

Making fewer trips over the field also means that equipment lasts longer and/or can cover more acres. In either case, machinery ownership costs per acre are reduced (Monson and Wollenhaupt, 1995). In addition, the size and number of machines required decline as the intensity of tillage or the number of operations is reduced. This can result in significant savings in operation and maintenance costs. Fewer trips alone can save an estimated $5 per acre on machinery wear and maintenance costs (CTIC, 1996). While new or retrofitted machinery may be required to adopt conservation tillage practices, machinery costs usually decline in the long run because a smaller complement of machinery is needed for high-residue no-till systems. Conservation tillage equipment designs have improved over the last decade and these improvements enhance the opportunity for successful conversion to a CRM system. Farm equipment manufacturers are now producing a wide range of conservation tillage equipment suitable for use under a variety of field conditions (Sandretto and Bull, 1996).

Reducing the intensity or number of tillage operations also lowers fuel and maintenance costs. Fuel costs, like labor costs, can drop nearly 60 percent per acre by some estimates (Monson and Wollenhaupt, 1995; Weersink and others, 1992). If fuel prices increase, conservation tillage practices become relatively more profitable.

Several studies report that on a range of soil types, higher residue tillage systems such as no-till and ridge-till result in greater economic returns for a given crop than lower residue systems. Even in some northern areas with heavy wet soils where no-till yields have sometimes been slightly lower, net returns have often been better because per-acre costs were lower (Doster and others, 1994; Fox and others, 1991).

The net returns on the entire operation can increase even if returns for a particular crop on a farm do not. For example, a tillage system that requires substantially less labor per acre and reduces returns per acre slightly but that permits application of the labor savings to more acres could result in larger total returns (Sandretto and Bull, 1996).

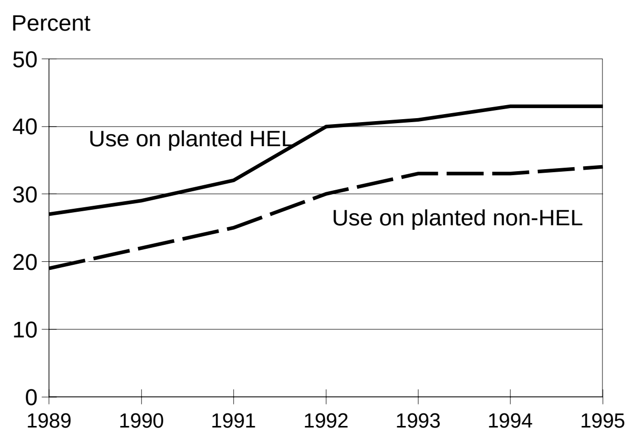
Policies and Programs Affecting CRM Adoption

The 1985 Food Security Act gave farmers an additional incentive to adopt CRM when it instituted the Conservation Compliance program to protect highly erodible land (HEL) by controlling erosion. Under the program, farmers who produce crops on HEL and fail to implement an approved conservation plan forfeit eligibility for most USDA farm program benefits (see chapter 6.4, *Conservation Compliance*). Crop residue management (including conservation tillage) is a key component in the conservation plans for around 75 percent of the 91 million acres of cultivated HEL subject to compliance. The 1990 Food, Agriculture, Conservation, and Trade Act further strengthened the Federal role of protecting soil and water resources. Besides increasing penalties for noncompliance, the Act established other programs that offer incentives to adopt practices such as CRM to improve water quality or control erosion (see chapter 6.1, *Conservation and Environmental Programs Overview).*

In 1991, USDA developed the Crop Residue Management Action Plan to assist producers with highly erodible cropland in implementing conservation systems that met the requirements of their approved conservation plans by the 1995 deadline. The plan increased the timely delivery of information, provided technical assistance to help land users install conservation systems, helped producers better understand the conservation provisions of farm legislation, and assisted them in maintaining their conservation plans and thus their eligibility for USDA program benefits. Crop Residue Management (CRM) alliances were established at the National, State, and local levels. The 20 State alliances, some of which remain active, included USDA agencies, agricultural supply industries, farm media, grower associations, commodity groups, conservation and environmental organizations, universities, and others interested in promoting the conservation of soil and water resources. USDA continues to provide assistance to farmers to meet conservation compliance requirements.

Adoption of conservation tillage practices, especially no-till, has been greater on HEL than on non-HEL (fig. 4.2.6). In 1995, conservation tillage was used on 43 percent of HEL acreage planted to major field crops in the primary producing States, compared with 34 percent for non-HEL. However, the rate of

Figure 4.2.6--Use of conservation tillage on HEL and non-HEL, major crops and growing States, 1989-95



See "Cropping Pracitces Survey" in the appendix for crops and States included.

Source: USDA, ERS, Cropping Practices Survey data.

Weed Control and Tillage

Crop yields can be significantly affected by weed populations. Traditional tools for controlling weeds have included crop rotations, crop or cover crop competition, and row crop cultivation and they play an important role in combination with modern pesticides to achieve effective pest control. These tools combined with scouting comprise the core of what has become known as integrated pest management (IPM). IPM is a systematic way of controlling pests (weeds, insects, and diseases) using a variety of techniques. The results from an effective IPM program often include higher profits due to savings from reduced pesticide applications and improved protection of the environment (CTIC, 1996).

Weed control problems vary among tillage systems because the nature of the weed population changes. An understanding of the response of weed species to tillage systems is essential in designing effective weed management programs (Martin, 1995). Actively tilling the soil before planting (and cultivating during the growing season for row crops) helps provide weed control in conjunction with herbicides. However, tillage also brings up dormant weed seeds and prepares a seedbed not only for the crop, but for weed seeds as well (Monson and Wollenhaupt, 1995). Tillage can also expand the perennial weed problem of some species by spreading their rhizomes and tubers (Kinsella, 1993). A challenge with no-till in some areas involves a gradual shift from annual weeds to several hard-to-control perennial weeds, including woody species and volunteer trees after 7-10 years (CTIC, 1996).

Mechanical cultivation for weed control is only feasible on the share of the cropland acreage planted with a row planter. The reported Cropping Practices Survey incidence of mechanical cultivation was fairly consistent across tillage systems except for higher use with ridge-till and considerably lower (one-third to one-half of the share of acres treated for other tillage systems) use with no-till. Ridge-till systems normally use mechanical cultivations during the season to rebuild and maintain the ridges in addition to controlling weeds.

Crop rotation can be an important tool for weed control because certain weeds are easier or more economical to control in one crop than another. For example, perennial grasses that are difficult to control in corn can be managed effectively in broadleaf crops such as cotton and soybeans (CTIC, 1996). Conversely, some broadleaf weeds are much easier to control in corn than in soybeans. A competitive crop that can achieve early shading of weeds can greatly improve weed control. The success of this system depends on obtaining a quick-closing crop canopy to shade emerging weeds and good stand establishment since skips allow some weeds to escape. Cover crops can accomplish this goal by reducing the amount of sunlight that reaches emerging weed seedlings (CTIC, 1996). In addition, crop rotations can often reduce the area needing treatment with pesticides and also decrease reliance on annual applications of the same pesticide; the latter pattern can increase pest resistance and reduce pesticide effectiveness.

Herbicide effectiveness depends on spraying at the right stage of growth and of plant stress, and under favorable weather conditions. Recommendations on the type and combination of herbicides and method of application for efficient weed control vary among tillage systems. The effective use of post-emergence herbicides most commonly employed in high residue situations requires careful and regular scouting and better knowledge of weed identification to facilitate appropriate herbicide selection. Herbicide application rates for ridge tillage were consistently lower than for other systems due to more prevalent banding, which uses smaller amounts of chemicals and more mechanical cultivation. Because no-till employs limited (or no) mechanical tillage, proper application of herbicides is essential for effective weed control. In addition, during the transition to higher residue systems, farmers often tend to increase slightly the amount of herbicide used as a risk aversion measure. The reported Cropping Practices Survey increase by no-till users in herbicide application (by weight) is due in part to the inclusion of an additional "burndown" herbicide treatment prior to planting as a substitute for mechanical weed control. However, successful no-till users find that herbicide costs generally decrease and become competitive with conventional tillage systems in 3-5 years (CTIC, 1996). Also, different management skills are required to control weeds with no-till or other high-residue tillage systems than with intensive tillage systems (CTIC, 1996). Crop residue management systems do not necessarily increase agricultural chemical requirements or application costs. The trend toward precision farming means that increasingly agricultural chemicals, including fertilizers and pesticides, will be carefully managed in a manner tailored to the site-specific conditions and the problems to be corrected. Improved input management is becoming necessary to ensure economic viability, maintain long-term productivity, and protect environmental quality.

increase in the use of conservation tillage on non-HEL was similar to that on HEL, suggesting that all producers are motivated by the potential of conservation tillage systems to reduce costs, improve efficiency, and/or increase soil productivity. Also, once a producer implements conservation tillage on HEL to stay in compliance, using the same equipment and techniques on his non-HEL makes good economic sense. The use of conservation tillage has leveled off in several regions since 1993 due in part to unusual weather patterns—primarily heavy rainfall—and cool planting conditions unfavorable for conservation tillage.

In passing the Federal Agriculture Improvement and Reform Act of 1996, Congress reaffirmed its preference for dealing with agricultural resource problems using voluntary approaches. The Act continued the Conservation Compliance Program and gave farmers greater flexibility in meeting requirements. The Act also established the Environmental Quality Incentives Program (EQIP) to replace previous financial and technical assistance programs and to better target assistance to areas most needing actions to improve or preserve environmental quality. While half of EQIP funding is to be directed to environmental practices relating to livestock production, the other half will be for other conservation improvements, which could include incentives (financial and technical assistance) for implementation of improved crop residue management. Directing the program toward management practices would favor crop residue management. Crop residue management, including conservation tillage, is a particularly cost-effective method of erosion control (requiring fewer resources than intensive structural measures such as terraces) that can be implemented in a timely manner to meet conservation requirements. The cost-savings from reduced fuel, labor, machinery, and time requirements, while usually maintaining or increasing crop yields, make greater adoption of CRM likely. (For more information on programs, see chapter 6.1, *Conservation and Environmental Programs Overview*.)

Barriers to CRM Adoption

Given the conservation and potential economic advantages of conservation tillage systems, and the promotion that has occurred, why aren't the systems used on more than 35 percent overall of U.S. cropland? First, adoption is the final step in a process that begins with becoming aware, moves to gaining information, then to trial, and finally to adoption. A number of farmers are in the reduced tillage transition stage between conventional intensive tillage and conservation tillage, or who are currently trying conservation tillage on part of their land, and will likely make further change. Second, there are particular soils and climatic or cropping situations where conservation tillage systems have not yet demonstrated that they can consistently produce good economic results. In these areas, most farmers are waiting for the development of improved systems. Further limiting factors include the additional management skill requirements and economic risk involved in changing systems, attitudes and perceptions against new practices, and, in some cases, institutional constraints.

Some farmers' attitudes against adoption of new technologies, including conservation tillage, derive from a reluctance to change from methods of production that have proven to be successful in terms of their own experience. The superiority of new techniques have to be demonstrated to a sufficient extent to offset exposure to the risks inherent in making a change from traditional methods. The perceived risks are critical because unusual weather or pest problems may be accepted as a normal occurrence with traditional methods but may be blamed on the new tillage system if they occur during the transition period. Consequently, the new technique may be unfairly discredited in the area for a long time if initial attempts result in failure.

Cultural and institutional factors can also constrain adoption. Some farmers or even whole communities demonstrate strong preferences for clean tilled fields as a sign of "good" management. The banker and/or landlord may be reluctant to permit a change in the way the land is farmed especially if they perceive more potential risk to crop yields and net returns during the transition.

Farmers are aware that a series of challenges exist with higher residue levels. These may include different (but not necessarily more serious) disease, insect, or weed problems; difficulties with more residue on the surface in proper seed, fertilizer, and pesticide placement; and, under certain conditions, particularly cool wet seasons, lower corn yields (CTIC, 1996). In addition, the land must be properly prepared for no-till (previous compaction and fertility problems need to be corrected first), and the transition period (2-4 years) can be very difficult as the farmer wrestles with learning how to adapt the new tillage system to his unique situation, especially if unusual weather or pest problems arise during the transition, because long-term benefits such as improved soil quality may take 4-7 years to be realized. However, in many situations, innovative farmers have found solutions to most of these problems or through experience have learned how to reduce their impact to tolerable levels until more acceptable solutions can be devised.

Farmers often face significant tradeoffs when choosing the most appropriate tillage system for their conditions. Higher residue systems generally allow less opportunity to correct mistakes or adjust to changed circumstances once the season is underway. Conservation tillage practices, with their higher levels of crop residue, usually require more attention to proper timing and placement of nutrients and pesticides, and in carrying out tillage operations. Nutrient management can become more complex with crop residue management because of higher residue levels and reduced options with regard to method and timing of nutrient applications. No-till in particular can complicate manure application and may also contribute to nutrient stratification within the soil profile from repeated surface applications without any mechanical incorporation. In those cases where nutrients cannot be utilized effectively by plant roots that are deeper in the soil profile, the problem can ususally be avoided by correcting prevalent nutrient deficiencies prior to the switch to no-till. With higher residue levels, however, evaporation is reduced and more water is maintained near the surface, which favors the growth of feeder roots near the surface where the nutrients are concentrated (Monson and Wollenhaupt, 1995). But in some instances, increased application of specific nutrients may be necessary and specialized equipment required for proper fertilizer placement, thereby contributing to higher costs.

Effects of CRM on Groundwater Quality

Enhanced infiltration of water under crop residue management raises concerns about whether there are greater adverse effects on groundwater than with conventional clean tillage. The issue continues to be analyzed; the difficulty of tracking a pesticide once it has been applied further complicates attempts to find an answer. While conservation tillage systems can change weed and insect problems and the kinds of herbicides and insecticides used, total use of pesticides does not change greatly when farmers convert to conservation tillage (tables 4.2.3-4.2.5) (Fawcett, 1987; Fawcett and others, 1994; Hanthorn and Duffy, 1983). Analyses of pesticide quantities by tillage system generally conclude that appropriate conservation tillage systems are no more likely to degrade water quality through chemical contamination than other tillage systems, and do not increase the risk of undesirable impacts from pesticides on human health and aquatic life (Baker, 1980; Baker, 1987; Baker and others, 1987; Baker and Laflen, 1979; Edwards and others, 1993; Fawcett and others, 1994; Melvin, 1995; Wagenet, 1987). For a specific site, the effects depend on a complex set of factors besides the infiltration rate, including properties of the chemicals applied, quantities applied, timing of application, method of application, and a variety of site specific factors (climatic, hydrologic, geologic, and topographic) (Onstad and Voorhees, 1987; Wagenet, 1987). Also, one has to consider what the cropping pattern and chemical use would be in the absence of CRM. In any situation, some of the factors may contribute to less effect and others to greater effect, with detailed analysis required to determine the net result. Some observations on these factors follow.

The potential for higher infiltration with conservation tillage creates an opportunity for groundwater degradation in some circumstances, such as for highly permeable sandy soils over shallow groundwater aquifers (Baker, 1987; CTIC, 1996; Wauchope, 1987). However, increased infiltration also normally dilutes the concentration of contaminants in the percolate to ground water (Bengtson and others, 1989; USDA, ERS, 1993).

The fate of applied chemicals is particularly dependent on the respective properties of the active ingredients, such as their adsorption, persistence, solubility, and volatility (Dick and Daniel, 1987; Fawcett, 1987; Melvin, 1995; Wauchope and others, 1992). Chemicals with high water solubility and low adsorption characteristics are highly mobile and possess the potential for loss through surface runoff or subsurface drainage (leachate) (Moldenhauer and others, 1995; USDA, ERS, 1993).

Pesticides that are strongly adsorbed to soil, sediment particles, or organic matter are protected from chemical or biological degradation and volatilization while adsorbed to these materials. Pesticides that are tightly held will not readily leach to ground water and will be found in surface-water runoff only under erosive conditions where the particles to which they are attached are washed off the fields. The soil adsorption property is a major factor affecting the pollution potential of a particular pesticide (Melvin, 1995; Wauchope and others, 1992; Weber and Warren, 1993).

The behavior of chemical compounds in the environment is also influenced by the application method. For example, whether a pesticide is applied to foliage or the soil or is incorporated into the soil makes a big difference in how easily the application deposits can be dislodged by rain, and thus be leached into the soil or transported in surface runoff. Soil incorporation physically lowers the susceptibility of a pesticide to volatilization and thereby increases its persistence (Wauchope and others, 1992).

Early pre-plant (EPP) herbicides are applied several weeks or months prior to crop planting. Their advantages include prevention of weed establishment, elimination of the need for burndown treatments at planting, reduction in the potential for herbicide carryover from one crop season to the next, and the spreading out of labor related to planting. However, there are disadvantages to EPP herbicides particularly on sloping or highly erodible cropland. Occasional heavy rains on unprotected sloping fields can cause soil erosion and high rates of surface runoff even with no-till systems, and chemicals (attached to soil particles or dissolved in runoff water) could enter waterways. Use of EPP herbicides should be avoided on sandy soils or other soil types with high leaching potential (CTIC, 1996). Pre-plant/pre-emergence herbicides depend on rainfall to trigger the active ingredients soon after application. Once in the soil, they must be mobile and persistent for a sufficient period of time to make contact with and destroy weed seedlings throughout the expected weed germination period. These enhanced mobility and persistence properties also facilitate the migration of such chemicals in the environment through surface-water runoff or percolation to ground water.

Burndown herbicides, more important in no-till systems, are nonselective and are used before or just after planting but prior to crop emergence. Post-emergence herbicides are successful in controlling problem weeds or escapes well into the growing season without damaging the crop or reducing yield potential and are generally unaffected by soil type or amount of crop residue on the surface. However, post-emergent application does depend on proper timing and correct identification of the target weeds. Post-emergence and burndown herbicides frequently have short or no residual soil effects (CTIC, 1996). They are generally less mobile and less persistent than pre-emergence herbicides and, therefore, less likely to migrate from their target. Pesticides applied to plant foliage, for instance, leave pesticide deposits that are highly vulnerable to photolysis and other degradation processes that reduce persistence and the potential for water pollution (Wauchope and others, 1992). For example, glyphosate and paraquat, although highly soluble, are strongly adsorbed to the targeted material or the soil and rapidly converted to relatively harmless degradation products that reduce their potential for contaminating ground water (Melvin, 1995; Moldenhauer and others, 1995).

The difference in chemical properties between the different classes of herbicides is important when considering the environmental impacts of herbicide use between tillage systems. Tillage systems that employ herbicides with lower mobility and shorter persistence are preferable from a water-quality standpoint to tillage systems that require herbicides with greater mobility and longer persistence (Melvin, 1995; Wauchope and others, 1992).

The inherent toxicity of the active ingredients and their degradation, the impact of these products on nontarget species, and their mobility and persistence in soil and water determine their relative impact on the environment. In addition, a specific active ingredient can be converted by environmental processes including hydrolysis, photolysis, and other processes into an important degradation product with different chemical properties (Wauchope and others, 1992). Tillage systems employing newer pesticides that are highly toxic to targeted species but are used at much lower rates may be more environmentally desirable. For a given chemical, the amount of active ingredient being dissipated into the environment is generally proportionate to the amount applied; as a result, lower application rates translate into reduced exposure of nontarget species to the side effects of these chemicals (Wauchope and others, 1992).

Author: Carmen Sandretto, (202) 219-0437 [carmens@econ.ag.gov]. Contributors: Leonard Bull and Richard Magleby.

References

Baker, J. L. (1980). "Agricultural Areas as Nonpoint Sources of Pollution." In M. R. Overcash and J. M. Davidson [eds.] *Environmental Impact of Nonpoint Source Pollution*. Ann Arbor Science Publications, Inc., Ann Arbor, MI, pp. 275-310.

Baker, J. L. (1987). "Hydrologic Effects of Conservation Tillage and Their Importance to Water Quality." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 113-124.

Baker, J. L. and H. P. Johnson (1979). "The Effect of Tillage System on Pesticides in Runoff from Small Watersheds." Trans. American Society of Agricultural Engineers, 22: 554-559.

Baker, J. L. and J. M. Laflen (1979). "Runoff Losses of Surface-applied Herbicides as Affected by Wheel Tracks and Incorporation." *Journal of Environmental Quality,* 8: 602-607.

Baker, J. L., T. J. Logan, J. M. Davidson, and M. R. Overcash (1987). "Summary and Conclusions." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 277-281.

Bengtson, R. L., L. M. Southwick, G. H. Willis, and C. E. Carter (1989). "The Influence of Subsurface Drainage Practices on Herbicide Loss." Paper 89-2130. American Society of Agricultural Engineers, St. Joseph, MI.

Bull, Len. (1993). "Residue and Tillage Systems for Field Crops" Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Staff Report No. AGES 9310, July.

Bull, Len, and Carmen Sandretto (1996). *Crop Residue Management and Tillage System Trends*, Natural Resources and Environment Division, Economic Research Service, U.S. Department of Agriculture. Statistical Bulletin No. 930.

Bull, Len, and Carmen Sandretto (1995). "The Economics of Agricultural Tillage Systems." *Farming for a Better Environment: A White Paper*. Soil and Water Conservation Society, Ankeny, IA, pp. 35-37.

Bull, Len, Herman Delvo, Carmen Sandretto, and Bill Lindamood (1993). "Analysis of Pesticide Use by Tillage System in 1990, 1991 and 1992 Corn and Soybeans." *Agricultural Resources: Inputs Situation and Outlook Report*, AR-32, ERS, USDA, October.

Clark, Richard T., James B. Johnson, and Jennifer Brundson (1994). "Economics of Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Northern Great Plains Region*. (W.C. Moldenhauer and A.L. Black, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 38.

Conservation Technology Information Center (1996). *A Checklist for U.S. Farmers*, West Lafayette, IN.

Dick, W. A. and T. C. Daniel (1987). "Soil Chemical and Biological Properties as Affected by Conservation Tillage: Environmental Implications." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 125-147.

Doster, D.H., T. W. Pritchard, D. R. Griffith, and S. D. Parsons (1994). "Tillage Economics, One Planter Farms." ID-191. Purdue University Cooperative Extension Service.

Edwards, William M. (1995). "Effects of Tillage and Residue Management on Water for Crops," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Appalachia and Northeast Region* (R.L. Blevins and W.C. Moldenhauer, eds.). USDA Agricultural Research Service, Conservation Research Report No. 41.

Edwards, William M., M. J. Shipitalo, L. B. Owens, and W. A. Dick (1993). "Factors Affecting Preferential Flow of Water and Atrazine Through Earthworm Burrows under Continuous No-till Corn." *Journal of Environmental Quality*. Vol. 22, No. 3.

Fawcett, Richard S. (1987). "Overview of Pest Management for Conservation Tillage Systems." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 19-37.

Fawcett, Richard S., Dennis P. Tierney, Brian R. Christensen (1994). "Impact of Conservation Tillage on Reducing Runoff of Pesticides into Surface Waters." *Journal of Soil and Water Conservation*. Vol. 49, No. 2.

Fox, G., A. Weersink, G. Sarwar, S. Duff, and B. Deen (1991). "Comparative Economics of Alternative Agricultural Production Systems: A Review." *Northeastern Journal of Agricultural and Resource Economics*. Vol. 30, No. 1.

Gadsby, Dwight M., Richard S. Magleby, and Carmen L. Sandretto (1987). "Why Practice Conservation." *Soil and Water Conservation News*. Vol. 8, No. 9.

Glenn, S. and J. S. Angle (1987). "Atrazine and Simazine in Runoff from Conventional and No-Till Corn Watersheds." *Agricultural Ecosystems and Environment*, 18: 273-280.

Griffith, D. R., E. J. Kladivko, J. V. Mannering, T. D. West, and S. D. Parsons (1988). "Long Term Tillage and Rotation Effects on Corn Growth and Yield on High and Low Organic Matter, Poorly Drained Soils." Agronomy Journal No. 4, Pages 599-605.

Griffith, D.R., J.F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Breitbach (1992). "Crop Response to Tillage Systems." In *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till.* Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA, pp. 25-33.

Hall, J. K., N. L. Hartwig, and L. D. Hoffman (1984). "Cyanazine Losses in Runoff from No-Tillage Corn in Living and Dead Mulches vs. Unmulched, Conventional Tillage," *Journal of Environmental Quality*, 13: 105-110.

Hanthorn, M. and M. Duffy (1983). "Corn and Soybean Pest Management Practices for Alternative Tillage Strategies." Publication No. IOS-2, USDA/ERS, Washington, D. C.

Helling, C. S. (1987). "Effect of Conservation Tillage on Pesticide Dissipation." T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, Michigan, pp. 179-187.

Hudson, E. H. and J. F. Bradley (1995). "Economics of Surface-Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Southeast Region* (G,W, Langdale and W.C. Moldenhauer, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 39.

Kinsella, Jim. (1993). "Notes on Weed Control with Herbicides in the Production of Row Crops." Presented to Conservation Technology Information Center Executive Meeting, March 30.

Martin, Alex R. (1995). "Weed Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region*. (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.

Melvin, Stewart W. (1995). "Effects of Crop Residue Management on Water Quality," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region* (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.

Mengel, D. B., J. F. Moncrief, and E. E. Schulte (1992). "Fertilizer Management," *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till.* Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA, pp. 83-87.

Moldenhauer, W.C., W.D. Kemper, and L.N. Mielke (1995). "Long-Term Effects of Tillage and Crop Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region* (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.

Monson, Mike and Nyle Wollenhaupt (1995). "Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region* (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.

Onstad, C. A. and W. B. Voorhees (1987). "Hydrologic Soil Parameters Affected by Tillage." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 95-112.

Sander, K. W., W. W. Witt, and M. Barrett (1989). "Movement of Triazine Herbicides in Conventional and Conservation Tillage Systems." In D. L. Weigmann [ed.] Pesticides in *Terrestrial and Aquatic Environments.* Virginia Water Resources Center and Virginia Polytechnic Institute and State University, Blacksburg, pp. 378-382.

Sandretto, Carmen and Len Bull (1996). "Conservation Tillage Gaining Ground," Agricultural Outlook, AO-232, Economic Research Service, U.S. Dept. Agr., August.

Siemens, John C. and D. Howard Doster (1992). "Costs and Returns." In *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till*. Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA, pp. 34-41.

U.S. Dept. of Agriculture, Economic Research Service (1993). "Water Quality Effects of Crop Residue Management." *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report*, AR-30, May.

Wagenet, R. J. (1987). "Processes Influencing Pesticide Loss with Water under Conservation Tillage," T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 189-204.

Wauchope, R. D. (1987. "Effects of Conservation Tillage on Pesticide Loss with Water." In T. J. Logan, J. M. David-

Recent ERS Reports on Crop Residue Management

"Conservation Tillage Gaining Ground," AO-232, August 1996 (Carmen Sandretto and Len Bull). This special article discusses recent trends in conservation tillage practice adoption and describes some of the benefits and limitations associated with their use on major field crops. Conservation tillage practices such as no-till, ridge-till, and mulch-till were expected to be used on a record-high 103 million acres in 1996 (more than one-third of U.S. planted cropland), with most of the growth due to rapid expansion in the adoption of no-till which nearly tripled between 1989 and 1995 to almost 41 million acres. Expanded use of no-till has been greater for row crops such as corn and soybeans than for small grains or sorghum.

Crop Residue Management and Tillage System Trends, SB-930, August 1996 (Len Bull and Carmen Sandretto). Trends in national and regional use of crop residue management show that conservation tillage use expanded from 72 million acres in 1989 to more than 99 million acres in 1994. Tillage systems use on major field crops is presented for 1988-94 and by surveyed States for 1994.

Soil Erosion and Conservation in the United States: An Overview, AIB-718, September 1995 (Richard Magleby, Carmen Sandretto, William Crosswhite, and C. Tim Osborn). This report provides background information on soil use, erosion, and conservation policies and programs; summarizes assessments of economic and environmental effects of erosion; and discusses policies and programs as well as options for their improvement.

"Analysis of Pesticide Use by Tillage System in 1990, 1991, and 1992 Corn and Soybeans," AR-32, October 1993 (Len Bull, Herman Delvo, Carmen Sandretto, and Bill Lindamood). This special article examines the relationship between pesticide use and tillage systems in the production of corn and soybeans in 1990, 1991, and 1992. Little difference between tillage systems was observed in the percentage of acres treated or in the number of herbicide treatments. Average pounds of herbicide active ingredients applied did not exhibit a consistent pattern across tillage systems over the three year period. Among tillage systems, about 40-50 percent of the herbicide acre-treatments were combination mixes of more than one active ingredient, but no-till was the exception with about 50-60 percent being combination mixes. Corn insecticide applications were not significantly different between tillage systems, although no-till acreage received lower application amounts for each year.

"Water Quality Effects of Crop Residue Management," AR-30, May 1993 (Carmen Sandretto). This special supplement points out that crop residue management in combination with other appropriate management strategies and the proper selection and use of chemicals can play a crucial role in protecting water quality. The movement of agricultural chemicals from the point of application to ground or surface waters depends on a complex set of interactions between a variety of site specific factors ranging from the climate and the hydrologic, geologic, and topographic characteristics of the land surface, and the chemical carriers—sediment, surface runoff, and subsurface drainage water—and the respective properties of the active ingredients of the applied chemicals, such as their adsorption, persistence, solubility, and volatility characteristics.

son, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 205-215.

Wauchope, R. D.,T. M. Buttler, A. G. Hornsby, P. W. M. Augustijn Beckers, and J. P. Burt (1992). The SCS/ARS/CES Pesticide Properties Database for Environmental Decision-making. Published as Volume 123 (164 pages) of *Reviews of Environmental Contamination and Toxicology* by Springer-Verlag, NY.

Weber, J. B. and R. L. Warren (1993). "Herbicide Behavior in Soils: A Pesticide/Soil Ranking System for Minimizing Ground Water Contamination." *Proceedings of the Northeastern Weed Science Society*, 47.

Weersink, A., M. Walker, C. Swanton and F.E. Shaw (1992). "Costs of Conventional and Conservation Tillage Systems." *Journal of Soil and Water Conservation*. Vol. 47, No. 4.

Young, Douglas L., Tae-Jin Kwon, and Frank L. Young (1994). "Profit and Risk for Integrated Conservation Farming Systems in the Palouse." *Journal of Soil and Water Conservation*. Vol. 49, No. 6.

4.3 Cropping Management

Rotating crops can help maintain soil fertility and reduce the need for chemical fertilizers and pesticides. Most corn and soybeans are grown in rotation with each other or other row crops. The most predominant wheat rotation is wheat-fallow-wheat, while monoculture is the most common practice in cotton. The primary factor determining a farmer's choice of cropping pattern is the rate of return; other contributing factors include agroclimatic conditions, farm programs, conservation programs, and environmental regulations. Crop rotations, generally. will prevail over monoculture only if more profitable.

Contents

Rotating crops to help maintain soil fertility, reduce soil erosion, and control insects and diseases (by disrupting the life cycle of insect pests, weeds, and plant pathogens) was much more common before the mid-1950s, when farmers increased their reliance on insecticides, herbicides, and fungicides, and commercial fertilizers as a means of sustaining or increasing yields. More recently, public concerns about the hazards of these chemicals in the food chain and in ground and surface water have prompted policy makers, universities, and other private sector decision makers to examine ways to reduce the use of these chemicals in agricultural production. Consequently, farmers are increasingly considering production alternatives, including crop rotation, to reduce adverse environmental consequences.

Farmers choose between crop rotation (planting different crops successively in the same field) and monoculture (or continuous cropping) based on agro-climatic and economic factors. This choice, in turn, frequently affects the use of fertilizers and pesticides. The Cropping Practices Survey, which collects a 3-year cropping history, indicates various cropping patterns and how they affect input use in the production of corn, soybeans, cotton, and wheat—the four major commercial crops (see box, "Cropping Pattern Definitions").

Environmental Benefits of Crop Rotations

The potential benefits of crop rotation include improved fertility by including nitrogen fixing legumes in crop rotation; reduced incidence of plant diseases, insects, and weeds; reduced loss of soil, nutrients, and moisture; increased water-holding capacity of the soil through increased organic matter; and reduced water pollution often associated with runoff and leaching. However, short-term benefits accruing to the farmer may not be sufficient to prevent a reduction in earnings from substituting one crop with another, unless the new crop can by used by onfarm livestock.

Crop rotations improve soil conditions so that in most cases yields of grain crops will increase beyond those achieved with continuous cropping (Heichel, 1987; Power, 1987). Corn following wheat, which is not a

Cropping Pattern Definitions

The following definitions were applied to 3-year crop sequence data reported in the Cropping Practices Survey to represent a cropping pattern for each sample field. The data were limited to the current year's crop plus the crops planted the previous 2 years on the sample field.

Monoculture or continuous same crop—A crop sequence where the same crop is planted for 3 consecutive years. Small grains (wheat, oats, barley, flax, rye, etc.) or other close-grown crops may be planted in the fall as a cover crop. The rotation excludes soybeans double-cropped with winter wheat.

Continuous row crops—A crop sequence, excluding continuous same crop, where only row crops (corn, sorghum, soybeans, cotton, peanuts, vegetables, etc.) are planted for 3 consecutive years. Small grains or close-grown crops may be planted in the fall as a cover crop.

Mix of row crops and small grains—A crop sequence where some combination of row crops and small grains are planted over the 3-year period. The rotation excludes soybeans double-cropped with winter wheat.

Hay, pasture, or other use in rotation—A crop sequence that includes hay, pasture, or other use in 1or more previous years. The rotation excludes any of the above rotations and any area that was idle or fallow in one of the previous years.

Idle or fallow in rotation—A crop sequence that includes idle, diverted, or fallowed land in 1 or more of the previous years.

Double-cropped soybeans—A crop sequence, limited to soybean acreage, where winter wheat was planted the previous fall.

legume, produces a greater yield than continuous corn when the same amount of fertilizer is applied (Power, 1987). Yields following legumes are often 10 to 20 percent higher than continuous grain regardless of the amount of fertilizer applied (National Research Council, 1989).

Crop rotations can also control insects, diseases, and weeds, particularly those pests that attack plant roots. Crop rotations aid in insect management by replacing a susceptible crop with a non-host crop. Rotating corn with soybeans may reduce soil population of corn rootworm larvae and thereby reduce the need for insecticide treatment. In the southern United States, when peanuts are rotated with cotton and corn, the nematode population drops. If cotton is rotated with corn or grown continuously, then the sting nematode can build up to devastating levels in a few years.

Crop rotations can also help control soil erosion. Closely sown field grain crops such as wheat, barley, and oats, as well as most hay and forage crops, provide additional vegetative cover to reduce soil erosion. In addition, these crops also compete with broadleaf weeds and may help control the weed infestation in subsequent crops since they are usually harvested before weeds reach maturity and produce seed.

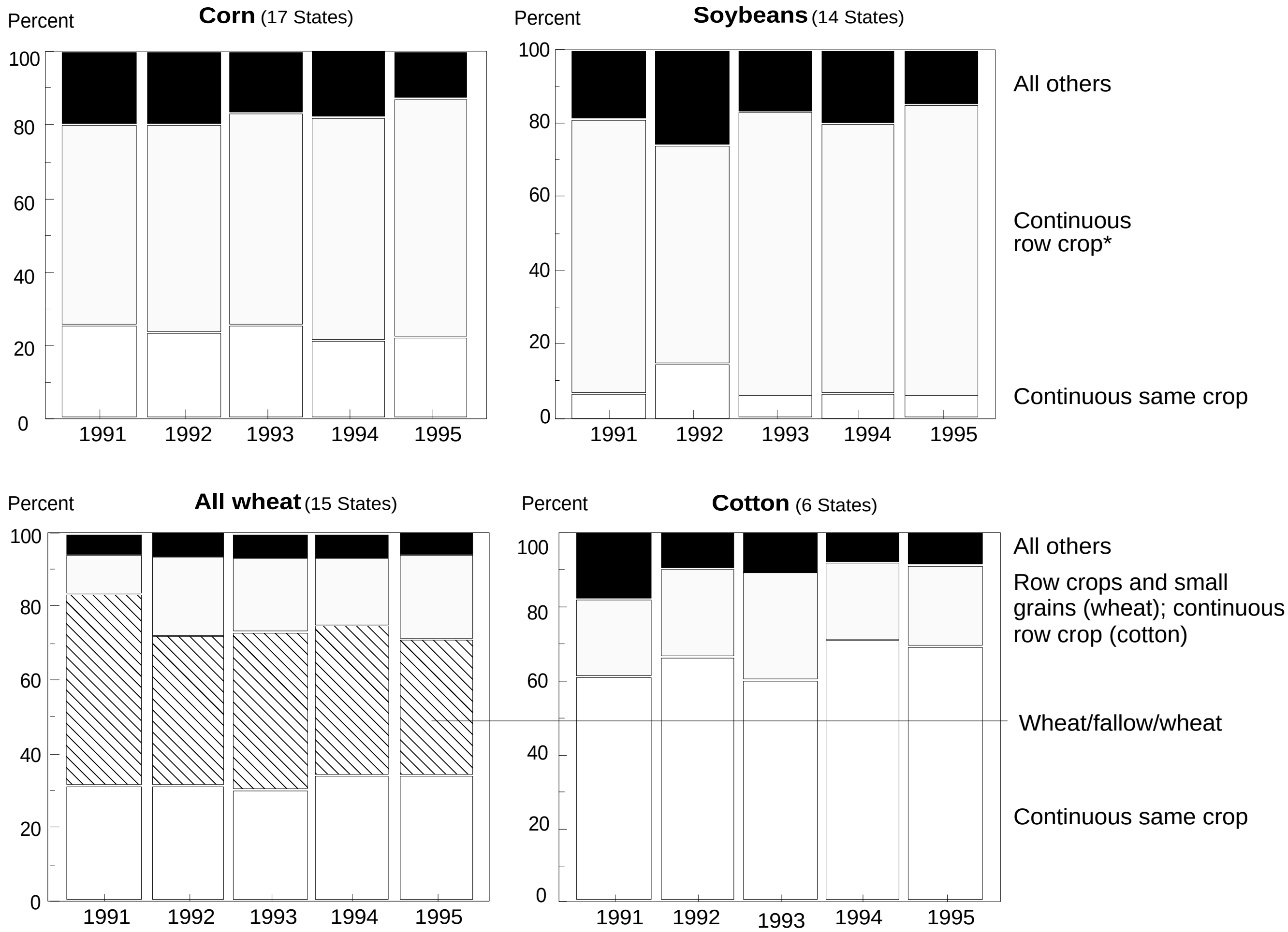
Finally, all rotations promote diversification and can provide an economic buffer against price fluctuations for crops and production inputs. Diversification also helps reduce the vagaries of weather and disease and pest infestations.

Cropping Patterns on Land Producing Major Crops

Corn. Cropping Practices Survey data (see appendix for a description of the survey) indicate that for most areas of the United States, farmers varied the crops planted from year to year. In the 17 major corn growing States, about 63 percent of the corn acreage in 1995 was in rotation with soybeans or other row crops (table 4.3.1, fig. 4.3.1). Twenty-one percent was in continuous corn. Only 9 percent of corn acreage was in rotation with small grains, hay, or pasture and the remaining 7 percent was idle for at least 1 of the 2 preceding years. Over 1991-95, corn monoculturing appears to have declined slightly, while continuous row cropping has slowly but steadily increased (fig. 4.3.1).

Soybeans. Nearly three-fourths of soybean acreage in 14 major producing States in 1995 was reported in rotation with corn or other row crops (fig. 4.3.1, table 4.3.1). Continuous soybeans (monoculture) occurred on only 10 percent of the acreage. Farmers in the

Figure 4.3.1--Trends in major cropping patterns, 1991-95



* Corn mostly in rotation with soybeans.
Source: USDA, ERS, Cropping Practices Survey data.
For States included, see "Cropping Practices Survey" in the appendix.

Northern States mostly rotated soybeans with corn, whereas Southern farmers tended to plant continuous soybeans. Over 1991-95, the rotation of soybeans with other row crops increased, while the proportion in continuous soybeans remained low (fig. 4.3.1).

Cotton. In 1995, 68 percent of the cotton acreage in the 6 major cotton producing States followed a continuous cotton pattern (fig. 4.3.1, table 4.3.1). Continuous row crops accounted for another 21 percent. Over 1991-95 period, cotton monoculturing increased.

Wheat. The two predominant cropping patterns in the major wheat growing States were continuous wheat (34 percent of total wheat acreage) and wheat-fallow-wheat (37 percent) (fig. 4.3.1, table 4.3.1). Much of the wheat in the United States is grown in the Great Plains, where moisture is limited. Farmers in these areas prefer the moisture-conserving wheat-fallow-wheat rotation. However, wheat with row crops is mostly grown in the more humid regions such as Illinois, Missouri, Ohio, and Minnesota. The rotation of wheat with row crops and other small grains (23 percent in 1995) may be increasing, while a wheat-fallow-wheat pattern may be declining (fig. 4.3.1). Also, the share of wheat acreage in continuous wheat was up slightly in 1994 and 1995 compared with 1991-93.

Rotations and Chemical Use

Herbicide use. Most acres in corn, cotton, and soybeans received one or more herbicide treatments, regardless of the cropping pattern (table 4.3.1). Some differences existed among patterns in the annual pounds of active ingredient applied per treated acres but these have not been consistent from year to year

Table 4.3.1—Cropping patterns and associated chemical use in major producing States, 1995[1]

Crop/Item	3-year crop sequence[2]: Continuous: Same crop	Continuous: Row crops	Continuous: Small grains	Combination row crops and small grains	Idle or fallow	Hay, pasture or other crops	Double-cropped w/wheat or soybeans	Total
Corn: (17 States)								
Planted acres (1,000 ac.)	13,581	40,050	n/a	1,770	4,480	4,224	n/a	64,105
Planted acres treated with:				*Percent of planted acres*				
Nitrogen	96.7	98.2	n/a	90.2	98.1	95.2	n/a	97.4
Phosphate	76.6	82.3	n/a	65.5	77.9	86.6	n/a	80.6
Potash	55.3	75.4	n/a	36.9	61.6	82.6	n/a	69.6
Herbicides	95.8	98.2	n/a	93.7	94.2	93.0	n/a	97.0
Insecticides	58.7	18.9	n/a	4.2	24.7	22.4	n/a	27.5
Average application rates for:				*Pounds a.i. per treated acre*				
Nitrogen	138	136	n/a	85	120	82	n/a	130
Phosphate	43	63	n/a	37	52	44	n/a	56
Potash	63	85	n/a	43	74	60	n/a	78
Herbicides	2.54	2.81	n/a	2.14	2.65	2.50	n/a	2.71
Insecticides	0.80	0.67	n/a	1.03	0.75	0.97	n/a	0.75
Soybeans: (14 States)								
Planted acres (1,000 ac.)	5,088	37,932	n/a	2,293	2,311	763	3,454	51,840
Planted acres treated with:				*Percent of planted acres*				
Nitrogen	18.0	15.3	n/a	23.6	10.7	19.3	29.9	17.0
Phosphate	27.4	19.1	n/a	36.5	21.4	33.8	31.5	22.0
Potash	30.2	23.0	n/a	35.4	23.7	33.8	36.5	25.3
Herbicides	93.7	99.0	n/a	91.4	95.1	90.2	92.9	97.5
Insecticides	7.8	1.0	n/a	1.3	0.4	id	4.1	1.8
Average application rates for:				*Pounds a.i. per treated acre*				
Nitrogen	32	27	n/a	26	15	35	42	29
Phosphate	44	57	n/a	49	38	56	56	54
Potash	71	91	n/a	55	73	85	79	85
Herbicides	1.28	1.07	n/a	1.42	1.33	0.66	1.22	1.12
Insecticides	0.56	0.39	n/a	0.64	0.58	id	0.57	0.49
Cotton: (6 States)								
Planted acres (1,000 ac.)	7,938	2,453	n/a	205	781	274	n/a	11,650
Planted acres treated with:				*Percent of planted acres*				
Nitrogen	85.3	93.0	n/a	95.1	79.6	87.6	n/a	86.8
Phosphate	52.6	72.5	n/a	69.6	40.4	55.3	n/a	56.3
Potash	44.0	35.1	n/a	44.6	20.6	34.0	n/a	40.3
Herbicides	98.5	95.8	n/a	83.4	95.7	100.0	n/a	97.5
Insecticides	73.2	81.7	n/a	84.4	81.0	92.3	n/a	76.2
Average application rates for:				*Pounds a.i. per treated acre*				
Nitrogen	93	91	n/a	137	123	148	n/a	96
Phosphate	40	47	n/a	46	48	59	n/a	43
Potash	53	47	n/a	57	31	40	n/a	51
Herbicides	2.16	1.78	n/a	2.17	1.38	2.16	n/a	2.03
Insecticides	2.36	2.28	n/a	3.18	2.27	2.66	n/a	2.36
All wheat: (15 States)								
Planted acres (1,000 ac.)	17,982	n/a	1,949	11,934	19,423	1,262	414	52,965
Planted acres treated with:				*Percent of planted acres*				
Nitrogen	87.8	n/a	95.8	96.0	80.9	72.3	86.1	87.0
Phosphate	58.2	n/a	92.5	81.8	52.6	57.6	56.7	62.7
Potash	9.8	n/a	22.7	43.7	8.6	13.3	36.3	17.7
Herbicides	63.1	n/a	95.3	67.4	74.4	83.6	45.1	69.7
Insecticides	8.8	n/a	1.7	0.8	1.2	id	id	3.7
Average application rates for:				*Pounds a.i. per treated acre*				
Nitrogen	62	n/a	73	79	59	57	74	64
Phosphate	30	n/a	29	44	27	36	49	33
Potash	21	n/a	12	50	25	45	60	38
Herbicides	0.29	n/a	0.67	0.47	0.44	0.49	0.10	0.41
Insecticides	0.36	n/a	0.50	0.30	0.38	id	id	0.36

Id = Insufficient data. n/a = Not applicable. [1] For States included, see "Cropping Practices Survey" in the appendix. [2] See box, "Cropping Pattern Definitions." Source: USDA, ERS, Cropping Practices Survey data.

and may reflect regional and weather variations. Continuous wheat showed the lowest percentage of wheat acres treated with herbicides, but this may be due to the agroclimatic conditions in the region where this pattern predominates.

Insecticide use. Insecticide use on continuous corn occurred much more frequently than on corn in rotations (table 4.3.1). Higher use of insecticides on continuous corn is needed to reduce the build up of insects, especially corn rootworm, which monoculture tends to encourage. Alternating crops with corn reduces the need for insecticide treatment because rootworms and other populations are not allowed to build up. Three-fourth of cotton acres were treated with insecticide, with little difference among patterns in average amount applied. Soybeans usually are not treated with insecticide. While only a small part of wheat acreage was treated with insecticides, the proportion of continuous wheat treated was higher than that for wheat in various rotations.

Fertilizer use. Most corn, cotton, and wheat acres received nitrogen fertilizer in 1995, with smaller proportions receiving phosphate and potash (table 4.3.1). Cropping patterns generally did not influence average annual pounds applied except nitrogen use was higher for continuous corn than for some rotations, and lower for continuous cotton than for some rotations.

Factors Affecting Cropping Patterns

The primary factor determining a farmer's choice of cropping pattern is the rate of return; other contributing factors include agroclimatic conditions, farm programs, conservation programs, and environmental regulations. Crop rotations, generally, will prevail over monoculture only if more profitable as in Iowa, where corn-soybeans-corn was shown to yield $40 per acre more than continuous corn (Duffy, 1996).

Climate, rainfall, environmental, and economic conditions divide the United States into very distinct agroclimatic regions, with each region's conditions determining its needs and ability to rotate crops. For example, the level and the variability of rainfall in a given area determine the usefulness of legumes in a rotation. Alfalfa and other deep-rooted legumes can deplete the subsoil moisture to a greater depth than corn. As a result, in arid and semi-arid regions and in subhumid and humid regions during drought, the inclusion of these legumes in a rotation may reduce the yields of the following corn or other crops. Under irrigated conditions or in areas of abundant rainfall, however, legumes in rotation with cash grains will boost yield and reduce the need for fertilizer by providing for some or all of the nitrogen needed by corn or small grains (National Research Council, 1989).

Federal policies often unintentionally discourage the adoption of crop rotations. For example, commodity programs that restricted base acreage to one or two crops encouraged monoculture. To reduce this unintended effect, the 1990 Farm Act eliminated deficiency payments on 15 percent of participating crop base acres known as Normal Flex Acreage (NFA), regardless of the crops planted on them (with a few fruit and vegetable exceptions). As a result, many farmers flexed out of monoculture or idled the marginal acreage. The extent of flexing out varied by type of crop base, depending on expected relative market return. For example, oats appeared to be the least profitable program crop during 1991-94 as almost half of its NFA was flexed to another crop. The 1996 Farm Act allows 100 percent flexing (again with a few fruit and vegetable exceptions).

Under the 1985 and subsequent farm acts, highly erodible land (HEL) used for crops requires a conservation plan to qualify for USDA farm program benefits (see chapter 6.4, *Conservation Compliance*, for more detail). Planting crops in rotation can reduce erosion and is a part of many conservation plans for HEL. Indeed, more HEL in corn in 1995 was in rotation (18 percent) than was non-HEL (12 percent) (table 4.3.2). Also more winter, spring, and durum wheat (50, 64, and 46 percent respectively) on HEL was in a fallow or idle rotation than non-HEL (34, 20, and 44 percent).

Author: Mohinder Gill, (202) 219-0447 [mgill@econ.ag.gov]. Contributor: Renata Penn.

References

Brust, G.E., and B.R. Stinner (1991). "Crop Rotation for Insect, Plant Pathogen, and Weed Control", *CRP Handbook of Pest Management in Agriculture,* Editor David Pimentel, Second Edition, Volume 1. CRC Press Inc. pp.217-230.

National Research Council (1989). *Alternative Agriculture*, National Academy Press, Washington D.C. pp. 135-150.

U.S. Department of Agriculture, Economic Research Service (1991). *Agricultural Resources: Situation and Outlook Report*, AR-24. pp.39-46.

Daberkow, Stan. G., Jim Langley, and E. Douglas Beach (1995). "Farmers' Use of Flex Acres", *Choices, The Magazine of Food, Farm, and Resource Issues.*

Table 4.3.2—Cropping patterns on highly and non-highly erodible land in major producing States, 1995

Category	Corn (17 States	Soybeans (14 States)	Cotton (16 States)	Winter wheat (11 States)	Spring wheat (4 States)	Durum wheat (ND)	Total
Planted acres (1,000)[1]	64,105	51,840	11,650	34,265	15,750	2,950	180,560
Erodibility:				*Percent of planted acres*			
Highly erodible land (HEL)	18	15	20	34	26	24	21
Land not highly erodible	78	77	70	63	71	75	74
Land not designated	4	8	10	3	3	2	5
Three-year crop sequence on HEL:				*Percent of HEL planted acres*			
Continuous same crop	25	6	84	40	20	22	29
Continuous row crops	58	78	10	n/a	n/a	n/a	34
Continuous small grains	n/a	n/a	n/a	id	2	15	
Row crop and small grains[2]	3	9	1	10	14	15	8
Idle or fallow in rotation	11	7	4	50	64	46	28
Hay or other crops in rotation	4	id	id	id	id	id	1
Three-year crop sequence on non-HEL:				*Percent of non-HEL planted acres*			
Continuous same crop	22	10	67	45	15	23	24
Continuous row crops	67	74	24	n/a	n/a	n/a	53
Continuous small grains	n/a	n/a	n/a	id	12	12	1
Row crop and small grains[2]	3	11	2	20	52	20	10
Idle or fallow in rotation	7	4	7	34	20	44	12

n/a = not applicable. Id = insufficient data. Percentages may not add to 100 due to rounding.
[1] For the States included, see "Cropping Practices Survey" in the appendix. [2] Includes double-cropped with wheat or soybeans.
Source: USDA, ERS, Cropping Practices Survey data.

Zulauf, Carl, and Luther Tweeten (1996). “The Post-Commodity-Program, World, Production Adjustments of Major U.S. Field Crops”, *Choices, The Magazine of Food, Farm, and Resource issues.*

Conversation with Michael Duffy (Sept. 30.1996). Department of Economics, Iowa State University, 560 Heady Hall, Ames, Iowa 50011.

Heichel, G.H (1987). Legumes as a source of nitrogen in conservation tillage system. pp 29-35 in *The Role of Legumes in Conservation Tillage System*, J.F. Power, ed. Ankeny, Iowa: Soil Conservation Society of America.

Power, J.F (1987). Legumes:” Their Potential role in agricultural production”, *American Journal of Alternative Agriculture* 2(2): 69-73.

4.4. Pest Management

Insects, disease, and weeds cause significant yield and quality losses to U.S. crops, and farmers currently rely on pesticides to combat this damage. However, many scientists now recommend greater use of biological and cultural pest management methods, and biological products, such as Bacillus thuringiensis, have recently captured a small share of the pest control market. Government programs to encourage the development and use of biological and cultural methods include areawide pest management, integrated pest management (IPM), national organic standards development, and regulatory streamlining for biologicals.

Contents

For nearly four decades, the majority of U.S. farmers have relied on synthetic pesticides as their primary method for managing most crop pests in most commodities. Farmers adopted synthetic pesticides quickly after their commercial introduction in the 1940's because they were inexpensive, effective, and easy to apply (MacIntyre, 1987). Biological and cultural control methods such as Bt applications and trap cropping, which use living organisms and strategic cropping to combat pest damage, are not as widely used (see glossary for definitions of terms and methods).

During the early 1990's, USDA's Economic Research Service (ERS), using a producer probability survey representing over 60 percent of U.S. crop production, began compiling a baseline on the uses of various chemical, cultural, and biological practices to control pests. According to these data, pesticides are used on the majority of crop acreage of most major commodities. Most growers also used scouting, economic thresholds, and other pesticide-efficiency techniques, but less than half reported the use of cultural and biological techniques. (For information on pesticide quantitities and active ingredients, see chapter 3.2, *Pesticides*.)

The National Research Council recently concluded that pest resistance and other problems created by pesticide use had created an "urgent need for an alternative approach to pest management that can complement and partially replace current chemically based pest-management practices" (National Academy of Sciences, 1985). Various government programs and activities are being initiated to encourage increased use of integrated pest management (IPM) and other strategies to reduce pesticide use and risks, and to promote research and implementation of biological and cultural controls (Jacobsen, 1996; Browner, 1993).

Why Manage Pests?

Approximately 600 species of insects, 1,800 plant species, and numerous species of fungi and nematodes are considered serious pests in agriculture (Klassen and Schwartz, 1991). If these pests were not managed, crop yields and quality would fall substantially, likely increasing production costs and food and fiber prices. In addition, producers with greater pest problems would become less competitive.

Cultural and biological techniques were the primary methods used to manage pests in agriculture for thousands of years. U.S. farmers began shifting to chemical methods upon the successful use of a natural arsenic compound to control Colorado potato beetles in 1867 (National Academy of Sciences, 1995) and the inception of USDA's chemical research program in 1881 (Klassen and Schwartz, 1991).

The increases in crop yields throughout this century have been partly credited to pesticide technology; the majority of U.S. crop acreage is now treated with pesticides. The benefits of pesticides, the value of production that would be lost if alternatives were less effective, and the additional pest management costs if alternatives were more expensive have been shown in numerous studies (Osteen, 1987). The costs of pesticide use to human health and the environment have been much more difficult to quantify. A preliminary Cornell study estimates that the costs from human pesticide poisonings, reduction of fish and wildlife populations, livestock losses, honey bee losses, destruction of beneficial insects, pesticide resistance, and other pesticide effects are $8 billion annually in the U.S. (Pimentel and others, 1992). An alternative method that is more expensive or less effective than pesticides might be economically justified when weighed against the indirect costs of pesticides (see box, "Why Reduce Reliance on Pesticides?").

Pest Management Systems and Practices

USDA cropping practices and chemical use surveys between 1990 and 1995 provide information about chemical, cultural, and biological pest management systems for five major field crops (corn, soybeans, wheat, cotton, and potatoes) and selected fruits and vegetables. About 60 percent of U.S. cropland planted to crops was represented in these annual surveys.

Pesticide-Based Management

Pesticides are applied annually to the majority of U.S. crop acreage. One or more pesticides are used to control weeds and other pests of major field crops, corn, soybeans, wheat, cotton, and potatoes (table 4.4.1), as well as most fruit and vegetable crops (table 4.4.2).

Corn. The largest crop in the United States is corn, and it exceeds any other crop in the number of acres treated with pesticides (table 4.4.1). At least some herbicide was applied to 98 percent of the corn area in the 10 surveyed States in 1995, up from 95 percent in 1990. While the total amount of herbicide applied per acre fell slightly, the number of herbicide treatments and number of different ingredients applied per acre increased. The use of more frequent treatments and additional ingredients reflects an increase in the number of treatments later in the growing season and the grower's need for more broad-spectrum weed control. Treatments applied later in the growing season are less likely to run off or leach and are more likely to be post-emergence herbicides, which are often less persistent in the environment. The amount of herbicide applied per acre has fallen with the increased use of low-rate sulfonylurea herbicides and with reduced-rate applications of atrazine and other older herbicides.

Less than one-fourth of the corn acreage received insecticides in 1995, and corn rootworm was the most frequently treated insect. Insecticide applied to the soil before or during planting kills hatching rootworm larvae and is a common control method, especially when corn is planted every year. Corn acreage treated with insecticides in 1995 was down 6 percentage points from 1990. This decline may be due to closer monitoring of insect and mite populations in the previous crop to decide if preventive treatments are needed.

Soybeans. Herbicides account for virtually all the pesticides used on the soybean crop. In the late 1980's, sulfonylurea and imidazolinone herbicides, which could be applied at less than an ounce per acre, began to replace older products commonly applied at 1 to 2 pounds per acre. They are now among the most commonly used soybean herbicides and have caused total herbicide use to drop. However, the number of acres treated and number of treatments per acre have increased, partly due to the growth in no-till soybean systems, which often replace tillage prior to planting with a preplant "burndown" herbicide to kill existing vegetation. The area treated with herbicides after planting increased from 52 percent to 74 percent from 1990 to 1995, while treatments before planting dropped only a few percentage points.

Wheat. Wheat is one of the largest field crops in the United States, in terms of acreage, and is the least pesticide-intensive. Wheat accounted for 29 percent of the surveyed acreage in 1994, but received only 4 percent of the pesticides. Herbicides were applied on about half of the winter wheat, the largest wheat crop, in 1995, up from only 34 percent in 1990. Winter wheat grows through the fall and winter, and many weeds germinating in the spring cannot compete with the established wheat. In contrast, spring wheat seedlings compete directly with weed seedlings in the spring, and nearly all of these crops receive herbicide treatments.

Why Reduce Reliance on Pesticides?

Concern about the side effects of synthetic pesticides began emerging in scientific and agricultural communities in the late 1940's, after problems with insect resistance to DDT. The public became concerned about the unintentional effects of pesticide use after Rachel Carson's book on bioaccumulation and other potential hazards was published in the 1960's. Many unintentional effects of pesticide exposure on nontarget species have been reported since then, including acute pesticide poisonings of humans (especially during occupational exposure) and damage to fish and wildlife, including species that are beneficial in agricultural ecosystems. Since the 1960's, some pesticides have been banned, others restricted in use, and others' formulations changed to lessen undesirable effects.

Human Health Impacts. The American Association of Poison Control Centers estimates that approximately 67,000 nonfatal acute pesticide poisonings occur annually in the United States (Litovitz and others, 1990). However, the extent of chronic health illness resulting from pesticide exposure is much less documented. Epidemiological studies of cancer suggest that farmers in many countries, including the United States, have higher rates than the general population for Hodgkin's disease, leukemia, multiple myeloma, non-Hodgkin's lymphoma, and cancers of the lip, stomach, prostate, skin, brain, and connective tissue (Alavanja and others, 1996). Emerging case reports and experimental studies suggest that noncancer illnesses of the nervous, renal, respiratory, reproductive, and endocrine systems may be influenced by pesticide exposure. Case studies, for example, indicate that pesticide exposure is a risk factor for several neurodegenerative diseases, including Parkinson's disease and amyotrophic lateral sclerosis, also known as Lou Gehrig's disease (Alavanja and others, 1993). A comprehensive Federal research project on the impacts of occupational pesticide exposure on rates of cancer, neurodegenerative disease, and other illnesses was begun about 4 years ago in North Carolina and Iowa; about 49,000 farmers who apply pesticides and 20,000 of their spouses, along with 7,000 commercial pesticide applicators, are expected to participate in the study (Alavanja and others, 1996).

Direct exposure to pesticides by those who handle and work around these materials is believed to pose the greatest risk of human harm, but indirect exposure through trace residues in food and water is also a source of concern (EPA, 1987). The effects of these pesticide residues on infants and children and other vulnerable groups have recently been addressed with a new legislative mandate in the Food Quality Protection Act of 1996 (see box, "Pesticide Tolerance and Dietary Risks" in chapter 3.2, *Pesticides*).

Environmental Quality. Documented environmental impacts of pesticides include: poisonings of commercial honeybees and wild pollinators of fruits and vegetables; destruction of natural enemies of pests in natural and agricultural ecosystems; ground- and surface-water contamination by pesticide residues with destruction of fish and other aquatic organisms, birds, mammals, invertebrates, and microorganisms; as well as population shifts among plants and animals within ecosystems toward more tolerant species.

Most insecticides used in agriculture are toxic to honeybees and wild bees, and costs related to pesticide damages include honeybee colony losses, honey and wax losses, loss of potential honey production, honeybee rental fees to substitute for pollination previously performed by wild pollinators, and crop failure because of lack of pollination (Pimentel and others, 1992). Approximately one-third of annual agricultural production in the United States is derived from insect-pollinated plants (Buchman and Nabhan, 1996), and flowering plants in natural ecosystems may not thrive because of fewer pollinators.

The destruction of the natural enemies of crop pests has led to outbreak levels of primary and secondary crop pests for some commodities, and pest management costs have increased when additional pesticide applications have been needed for these larger or additional pest populations. Measurable costs related to pesticide residues in surface- and groundwater include residue monitoring and contamination cleanup costs and costs of damage to fish in commercial fisheries. Birdwatching, fishing, hunting and other recreational activities have been affected by aquatic and terrestrial wildlife losses due to pesticide poisonings. An emerging issue is the environmental impacts of invertebrate and microorganism destruction because of the essential role they play in healthy ecosystems.

Pesticide Resistance. After repeated exposure to pesticides, insect, weed, and other pest populations in agricultural cropping systems may develop resistance to pesticides through a variety of mechanisms. The newer safety requirements for pesticide registration along with the increasing pace of pest resistance has raised doubts about the ability of chemical companies to keep up with the need for replacement pesticides. In the United States, over 183 insect and arachnid pests are resistant to 1 or more insecticides, and 18 weed species are resistant to herbicides (U.S. Congress, 1995). Cross-resistance to multiple families of pesticides, along with the need for higher doses and new pesticide formulations, is a growing concern among entomologists, weed ecologists, and other pest management specialists.

Emerging issues include the impact of endocrine-system disrupting pesticides on human health and wildlife, including potential reproductive effects and effects on child growth and development (EPA, 1997), and the impacts of exposure to pesticides, particularly the potential for synergistic impacts (Arnold and others, 1996).

Table 4.4.1—Pest management practices on major field crops in major producing States, 1990-95

Crop	Units	1990	1991	1992	1993	1994	1995
Corn (10 States):[1]							
Planted area	1,000 ac.	58,800	60,350	62,850	57,350	62,500	55,850
Area receiving herbicides	Percent	95	96	97	98	98	98
Before or at plant only	Percent	39	38	33	35	29	30
After plant only	Percent	29	34	36	37	38	38
Both	Percent	26	23	27	26	32	29
Avg. number of treatments/acre	Number	1.4	1.4	1.4	1.4	1.5	1.5
Avg. number of ingredients/acre	Number	2.2	2.1	2.3	2.3	2.5	2.4
Avg. amount applied	Lbs./ac.	3.24	2.97	2.98	2.94	2.79	2.76
Amount banded	Percent	7	7	9	8	8	6
Area receiving insecticides	Percent	32	30	29	28	27	26
Before or at plant only	Percent	26	23	23	22	19	18
After plant only	Percent	4	6	5	5	7	7
Both	Percent	2	2	1	1	1	1
Avg. number of treatments/acre	Number	1.1	1.1	1.1	1.1	1.1	1.1
Avg. number of ingredients/acre	Number	1.1	1.1	1.1	1.0	1.1	1.1
Avg. amount applied	Lbs./ac.	1.18	1.04	0.95	0.90	0.83	0.75
Area scouted for pests	Percent	na	na	na	65	77	na
Operator or family member	Percent	na	na	na	na	64	na
Chemical dealer	Percent	na	na	na	na	5	na
Commercial service	Percent	na	na	na	na	62	na
Other	Percent	na	na	na	na		na
Area under crop rotation	Percent	76	75	77	75	74	80
Area with cultivations for weed control	Percent	70	68	72	53	63	66
Soybeans (8 States):[1]							
Planted area	1,000 ac.	39,500	42,050	41,350	42,500	43,750	45,150
Area receiving herbicides	Percent	96	97	98	98	98	98
Before or at plant only	Percent	44	39	36	28	28	23
After plant only	Percent	20	26	28	30	29	32
Both	Percent	32	32	34	35	42	42
Avg. number of treatments/acre	Number	1.5	1.5	1.6	1.6	1.7	1.7
Avg. number of ingredients/acre	Number	2.3	2.3	2.4	2.5	2.7	2.7
Avg. amount applied	Lbs./ac.	1.39	1.27	1.14	1.11	1.14	1.09
Amount banded	Percent	6	5	5	5	4	4
Area with scouting for pests	Percent	na	na	na	70	76	na
Operator or family member	Percent	na	na	na	na	68	na
Chemical dealer	Percent	na	na	na	na	5	na
Commercial service	Percent	na	na	na	na	2	na
Other	Percent	na	na	na	na	1	na
Area under crop rotation	Percent	na	na	na	na	93	90
Area with crop cultivations for weed control	Percent	67	61	54	38	44	41
Winter wheat (11 States):[1]							
Planted area	1,000 ac.	38,900	31,000	33,990	35,500	32,930	32,670
Area receiving herbicides	Percent	34	26	31	40	46	54
Before or at plant only	Percent	3	3	1.5	3	4	4
After plant only	Percent	30	23	29	36	40	48
Both	Percent	1	1	0.5	1	1	2
Avg. number of treatments/acre	Number	1.1	1.1	1.1	1.1	1.1	1.1
Avg. number of ingredients/acre	Number	1.5	1.5	1.6	1.8	1.8	1.8
Avg. amount applied	Lbs./ac.	0.28	0.27	0.28	0.30	0.33	.25
Area with scouting for pests	Percent	na	na	na	na	na	80
Area under crop rotation	Percent	na	na	na	na	61	57
Spring wheat (4 States):[1]							
Planted area	1,000 ac.	15,800	13,500	17,350	16,950	17,250	15,750
Area receiving herbicide	Percent	91	92	88	96	95	95
Before plant only	Percent	1	3	6	4	4	2
After plant only	Percent	82	83	77	83	79	86
Both	Percent	8	7	5	9	11	7
Avg. number of treatments/acre	Number	1.2	1.2	1.2	1.2	1.2	1.2
Avg. number of ingredients/acre	Number	1.8	2.0	2.1	2.2	2.3	2.4

Continued--

Table 4.4.1—Pest management practices on major field crops in major producing States, 1990-95 (cont.)

Crop	Units	1990	1991	1992	1993	1994	1995
Spring wheat (cont.)							
Avg. amount applied	Lbs./ac.	0.52	0.47	0.49	0.49	0.52	0.54
Area with scouting for pests	Percent	na	na	na	na	na	82
Area under crop rotation	Percent	na	na	na	na	100	84
Cotton (6 States):[1]							
Planted area	1,000 ac.	9,730	10,860	10,200	10,360	10,023	11,650
Area receiving herbicides	Percent	95	92	91	92	94	98
Before or at plant only	percent	58	52	49	45	41	46
After plant only	Percent	6	5	9	10	6	7
Both	Percent	31	35	33	38	46	45
Avg. number of treatments/acre	Number	2.1	2.3	2.5	2.5	2.6	2.7
Avg. number of ingredients/acre	Number	2.3	2.5	2.7	2.7	2.7	2.8
Avg. amount applied	Lbs./ac.	1.79	2.01	2.11	2.01	2.23	2.03
Amount banded	Percent	33	35	33	31	27	28
Area receiving insecticides	Percent	na	66	65	65	71	76
Avg. number of treatments/acre	Number	na	3.1	4.5	4.9	5.7	6.2
Avg. number of ingredients/acre	Number	na	2.3	3.2	3.4	3.5	3.8
Avg. amount applied	Lbs./ac.	na	1.13	1.83	2.06	2.48	2.36
Area receiving other pesticides	Percent	na	56	47	64	67	57
Avg. number of treatments/acre	Number	na	1.8	1.6	1.6	1.7	2.1
Avg. number of ingredients/acre	Number	na	2.0	2.0	1.9	2.0	2.1
Avg. amount applied	Lbs./ac.	na	1.63	2.34	1.79	1.72	2.40
Area with scouting for pests	Percent	na	na	na	na	88	na
Operator or family member	Percent	na	na	na	na	30	na
Chemical dealer	Percent	na	na	na	na	10	na
Commercial service	Percent	na	na	na	na	40	na
Other	Percent	na	na	na	na	8	na
Area under crop rotation	Percent	na	na	na	na	31	32
Area with cultivations for weed control	Percent	97	94	92	96	98	98
Area with pheromones used to monitor pests	Percent	na	na	na	na	19	25
Area with pheromomes used to control pests	Percent	na	na	na	na	9	na
Area treated with purchased beneficial insects	Percent	na	na	na	na	2	1
Fall potatoes (11 States):[1]							
Planted area	1,000 ac.	1,087	1,123	1,064	1,114	1,140	1,147
Area receiving herbicides	Percent	81	81	82	82	84	86
Before or at plant only	Percent	16	13	14	14	16	10
After plant only	Percent	60	61	63	62	58	72
Both	Percent	6	7	5	7	10	5
Avg. number of treatments/acre	Number	1.3	1.4	1.3	1.3	1.4	1.4
Avg. number of ingredients/acre	Number	1.6	1.7	1.7	1.7	1.8	1.9
Avg. amount applied	Lbs./ac.	2.15	2.29	1.94	2.06	2.42	2.40
Amount banded	Percent	3	4	2	1	2	1
Area receiving insecticides	Percent	89	92	90	88	88	88
Before or at plant only	Percent	18	13	14	14	16	16
After plant only	Percent	52	58	60	59	59	53
Both	Percent	19	21	17	16	13	19
Avg. number of treatments/acre	Number	2.0	2.2	2.3	2.2	2.7	2.5
Avg. number of ingredients/acre	Number	1.8	1.9	2.0	2.0	2.1	1.9
Avg. amount applied	Lbs./ac.	3.15	2.81	2.89	2.90	3.49	2.55
Area receiving fungicides	Percent	69	69	72	76	80	85
Avg. number of treatments/acre	Number	2.7	2.7	3.1	3.4	4.2	6.1
Avg. number of ingredients/acre	Number	1.4	1.5	1.9	2.1	3.2	2.7
Avg. amount applied	Lbs./ac.	3.17	3.42	3.93	4.22	5.61	6.75
Area receiving other pesticides	Percent	34.6	44.9	43.1	52.9	59.9	57.1
Avg. number of treatments/acre	Number	1.3	1.3	1.4	1.3	1.4	1.6
Avg. number of ingredients/acre	Number	1.1	1.2	1.3	1.2	1.2	1.3
Avg. amount applied	Lbs./ac.	73.38	71.24	84.43	74.56	94.36	92.74
Area with scouting for pests	Percent	na	na	na	85	na	na
Area under crop rotation	Percent	97	97	97	97	96	98
Area with cultivations for weed control	Percent	91	95	93	93	93	94
Area treated with purchased beneficial insects	Percent	na	na	na	na	na	na

na = not available. [1] For States included, see "Cropping Practices Survey" in the appendix. Source: USDA, ERS, Cropping Practices Survey data.

Table 4.4.2—Fruit and vegetable acreage treated with pesticides, major producing States, 1992/93 and 1994/95

	Planted acres[1]	States surveyed[2]	Area receiving application						Total application 1994/95		
			1992/1993			1994/1995			1994/1995		
			Herbicide	Insect-icide	Fungicide	Herbicide	Insect-icide	Fungicide	Herbicide	Insect-icide	Fungicide
	1,000 ac.	*No.*	*Percent of acres*						*1,000 lbs.*		
Fruit:											
Grapes, all types	796	6	64	66	93	74	67	90	1,193	3,970	32,551
Oranges	760	2	94	90	57	97	94	69	3,466	40,263	1,962
Apples, bearing	345	9	43	99	88	63	98	93	567	10,733	4,624
Grapefruit	147	2	93	93	85	92	89	86	618	9,185	1.420
Peaches, bearing	144	8	49	99	98	66	97	97	182	2,023	5,029
Prunes	94	1	40	93	84	46	73	84	64	842	398
Avocados	73	1	50	12	10	24	9	1	35	14	8
Pears	68	4	44	98	92	65	96	90	96	3,310	1,388
Cherries, sweet	47	4	45	94	87	61	92	93	56	777	655
Lemons	48	1	71	88	14	83	73	64	141	1,280	106
Cherries, tart	47	4	49	98	99	67	94	98	45	93	930
Plums	44	1	70	89	79	48	75	71	36	562	303
Olives	38	1	67	27	33	54	14	30	58	108	59
Nectarines	36	1	84	98	95	82	97	96	84	98	95
Blueberries	30	4	75	91	81	73	86	87	50	127	222
Vegetables:											
Sweet corn, proc.	503	7	92	75	19	94	66	9	1,623	254	59
Tomatoes, proc.	323	1	90	81	92	76	71	86	442	219	9,817
Greenpeas, proc.	203	6	91	49	1	93	50	*	251	42	4
Lettuce, head	191	5	68	97	76	60	100	77	127	631	524
Snap beans, proc.	173	9	95	68	55	91	58	41	449	139	65
Watermelon	166	6	37	53	71	41	45	64	68	136	681
Sweet corn, fresh	164	12	75	84	41	79	81	36	328	627	203
Onion	128	9	86	79	83	88	76	89	760	174	887
Broccoli	111	4	58	95	31	67	96	36	242	287	48
Tomatoes, fresh	104	8	75	95	86	52	94	91	114	710	3,417
Carrots	101	9	67	37	79	72	34	71	117	58	483
Cantaloupe	98	5	44	78	73	41	82	41	42	103	636
Cucumbers, proc.	83	9	74	34	32	77	48	30	95	41	49
Asparagus	81	5	86	64	28	91	70	23	205	100	59
Snapbeans, fresh	71	7	52	77	62	60	79	63	62	120	504

*Applied on less than 1 percent of the acres.

[1] Fruit producers were surveyed in 1993 and 1995; vegetable producers were surveyed in 1992 and 1994. Planted acreage in the major producing States surveyed is for 1994 for vegetables and 1995 for fruit.

[2] The survey was conducted in major producing States during both survey periods; the set of minor producing States that were surveyed was modified slightly between survey years for about one-third of the commodities. For States included, see "Chemical Use Survey" in the appendix.

Source: USDA, ERS and NASS, Chemical Use Survey data.

Insecticide use fluctuates with cycles of pest infestation, but is generally well under 10 percent of wheat area. Large populations of Russian wheat aphid and other insect pests in 1994 caused winter wheat farmers to treat nearly 10 percent of their acreage with insecticides (Padgitt, 1996). Because disease-resistant varieties are used to combat many wheat diseases, fungicides are normally applied to less than 5 percent of the wheat acres.

Cotton. Cotton is one of the most pesticide-intensive field crops grown in the United States. In 1995, 98 percent of cotton acreage received herbicides, 76 percent received insecticides, and 57 percent received other types of pesticides. Herbicides and insecticides account for about 76 percent of the pesticide applied to cotton, while plant growth regulators, defoliants, and other pesticides used to aid harvesting account for most of the remainder. Cotton diseases treated with a fungicide account for only 1 percent of all pesticides used on cotton.

Insect infestation on cotton is much greater than it is for corn, soybeans, or wheat, partly due to its longer growing season and the winter survival rates of insect eggs and larvae in warmer climates where it is grown. Although boll weevil eradication programs have been successful in several Southern States, tobacco budworms, cotton boll worms, thrips, and the boll weevil prevail in other States and require frequent treatments. About two-thirds of the cotton acres are treated for insect pests, often with repetitive treatments. Significant increases in insecticide use have occurred annually during the 1990's. The average quantity of insecticides applied per acre more than doubled between 1991 and 1994, while the average number of treatments increased from 3.1 to 5.7 and the number of different insecticide products increased from 2.3 to 3.5. In Louisiana and Mississippi, 10 or more insecticide treatments are applied during the growing season.

For weed control, most cotton is treated with a combination of pre-emergence and post-emergence herbicides. Unlike corn, soybeans, and wheat, no new low-rate herbicides have become available for cotton, and producers continue to rely on herbicides registered during the 1950's and 1960's.

Potatoes. Potatoes are among the most pesticide-intensive crops for all types of pesticides. Herbicides, insecticides, and fungicides are each used to treat 85 percent or more of potato acreage, and recently over half of the acres have also been treated with a soil fumigant, growth regulator, defoliant, or harvest aid. While the share of potato acres receiving any pesticide type did not change much between 1990 and 1995, the intensity of treatments did increase for all pesticide types. Fungicides, which are used to treat early and late blight and other diseases, accounted for the largest increase in pesticide treatments. The average number of fungicide treatments per acre and the application rate both doubled between 1990 and 1994. Soil fumigants and defoliants account for the largest total quantity of pesticides used on potatoes, but are applied to the smallest area.

Other Vegetables and Fruits. Orchards, vineyards, and vegetable farms generally have much higher net returns per acre than farms that specialize in field crop production, and fruit and vegetable growers have found it profitable to use insecticides and fungicides. Between 90 and 98 percent of the acreage of the 5 largest fruit crops--grapes, oranges, apples, grapefruit, and peaches--received at least one treatment with an herbicide, insecticide, or fungicide in 1995, and the majority of acres were treated with all three types (table 4.4.2). Herbicides, insecticides, and fungicides were used to treat 97, 94, and 69 percent of the U.S. orange acreage in 1995, for example, and 63, 98, and 93 percent of the apple acreage. For most fruit crops, the volume of insecticides and fungicides used is generally higher than the volume of herbicides used.

Among other vegetables, herbicides and insecticides were used on 94 and 66 percent of processing sweet corn, the largest vegetable crop, in 1994. Herbicides and fungicides were used on 76 and 86 percent of the second largest crop, tomatoes grown for processing. Pesticide surveys from the 1960's and 1970's also showed the majority of fruit and vegetable acreage receiving pesticides (Osteen and Szmedra, 1989).

Consumer expectations of cosmetically perfect fruits and vegetables, with no blemishes from insects or disease, fuels insecticide and fungicide use. And fresh-market vegetable acreage often receives more pesticides than the processing market crop. For example, a larger share of the fresh-market sweet corn and tomato acreage received fungicide and insecticide treatments than sweet corn and tomatoes grown for processing (table 4.2.2).

Regional differences in rainfall, humidity, soil types, and other growing conditions help determine the severity of pest problems and the intensity of pesticide use. Insecticide applications on grapes in 1994/95 ranged from 17 percent of the crop area in Washington to 96 percent in Michigan (table 4.4.3). Processing sweet corn receiving insecticides ranged from 41 percent in Washington to 82 percent in Illinois.

Pest problems, and the available alternatives for managing pests, vary over time as well as by crop and region. For the top three fruit crops—grapes, oranges, and apples—total area treated with pesticides increased or stayed about the same between 1992/93 and 1994/95 (table 4.4.3). However, insecticide and fungicide applications to total acreage of the two top vegetable crops—processing sweet corn and tomatoes—dropped. While insect and disease pressure may have been lighter during the second survey, the availability of alternatives may have also

Table 4.4.3—Pesticide application on selected fruit and vegetable crops, by major producing State, 1992/93 and 1994/95

Crop and State	Planted acres[1]	Area receiving applications 1992/1993 Herbicide	1992/1993 Insecticide	1992/1993 Fungicide	1994/1995 Herbicide	1994/1995 Insecticide	1994/1995 Fungicide
	1000 ac.	*Percent of acres*					
Fruit:							
Grapes, all types	796	64	66	93	74	67	90
California	701	62	67	94	73	68	92
Washington	34	72	39	52	77	17	35
New York	33	81	64	99	85	78	94
Michigan	12	90	97	100	93	96	100
Pennsylvania	11	72	59	52	99	93	99
Oregon	5	52	3	99	70	18	95
Oranges	760	94	90	57	97	94	69
Florida	563	98	96	69	98	96	77
California	197	94	90	57	92	86	46
Apples, bearing	345	43	99	88	63	98	93
Washington	153	45	100	85	66	99	88
New York	58	33	100	100	63	99	99
Michigan	54	54	99	100	68	100	100
California	40	46	92	71	48	86	88
Pennsylvania	22	34	100	100	66	98	98
Oregon	9	66	98	98	73	99	96
South Carolina	4	18	100	100	84	99	99
Vegetables:							
Sweet corn, proc.	503	92	75	19	94	66	9
Wisconsin	161	92	68	11	95	62	3
Minnesota	143	94	81	40	95	80	20
Washington	75	87	85	*	86	41	*
Oregon	49	90	60	*	98	63	*
Illinois	37	98	99	50	97	82	20
New York	33	92	60	**	98	66	3
Michigan	7	93	93	*	88	77	*
Tomatoes, proc.	323	90	81	92	76	71	86
California	318	90	81	92	76	71	86
Michigan	5	90	82	99	85	88	100

*Applied on less than 0.5 percent of the acres.

**Insufficient reports to publish percent of area receiving.

[1] Fruit producers were surveyed in 1993 and 1995, vegetable producers in 1992 and 1994; planted acreage in the listed State is for 1994-95.

played a role. A large U.S. food processor, for example, sought in the early 1990's to reduce the amount and frequency of pesticide use among its growers, and has been encouraging the use of Bt, parasitic wasps, mating-disrupting pheromones, disease-forecasting systems, and other biological and pesticide-reducing technologies (Orzalli, Curtis, and Bolkan, 1996).

Pesticide-Efficiency Tools

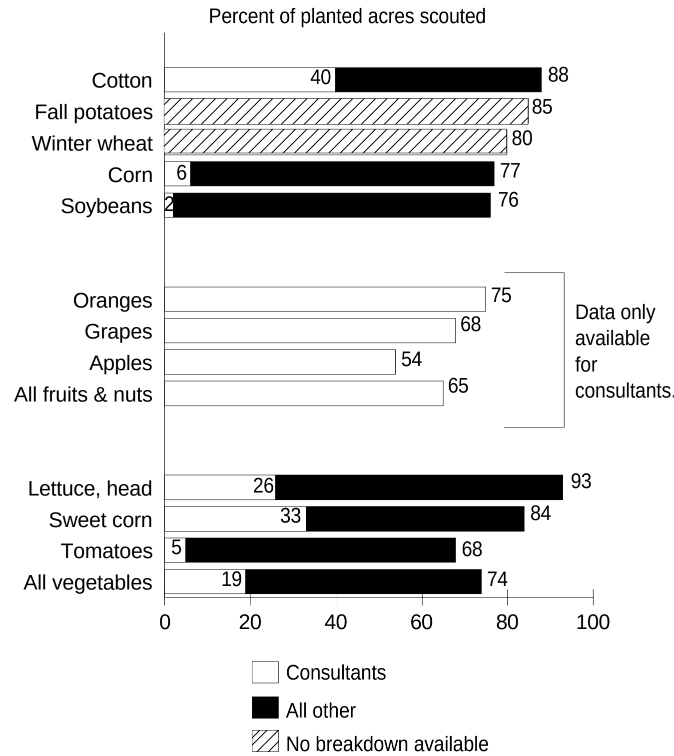
Entomologists have developed pest scouting, economic thresholds, and other tools to help producers determine when to make pesticide applications, which pesticides to use, and how much to use, and "expert systems" have integrated these tools into decision management software. Several new chemical-efficiency technologies—including precision farming and herbicide-tolerant crops—are just now being developed and commercialized. While these tools generally rely on pesticides, they may lower risks through lower rates, less toxic materials, or fewer applications.

Scouting and Economic Thresholds. Entomologists have been developing scouting techniques to monitor the populations of major insect and other arthropod pests for several decades. Field trials were conducted to determine the crop-damage functions associated with these pests in order to set economic thresholds--pest population levels above which economic damage to the crop would occur without pesticide application. These scouting techniques and thresholds were designed to replace routine, calendar-based insecticide applications.

While scouting techniques and thresholds have been developed for most major insect pests in agriculture, weed scientists and ecologists have only recently begun exploring whether economic thresholds are applicable for weed management (Coble and Mortensen, 1992). Economic thresholds are rarely used for plant pathogens since infections generally spread too quickly to use fungicides after the disease is detected. However, disease prediction models that result in disease advisories for some major fruit and field crops have been developed and commercialized.

Scouting and threshold use is widespread in specialty crop production (Vandeman and others, 1994). Nearly two-thirds of the U.S. fruit and nut acreage and nearly three-quarters of the vegetable acres in the surveyed States were scouted for insects, mostly by chemical dealers, crop consultants, and other professionals (table 4.4.4, fig. 4.4.1). Growers reported using thresholds as the basis for making pesticide treatment decisions on virtually all of these scouted acres (Vandeman and others, 1994). Potato growers reported that 85 percent of their acreage was scouted in 1993 (table 4.4.1), and thresholds were used in making nearly three-quarters of their insecticide application decisions. Growers of two-thirds to three-fourths of corn and soybeans reported scouting, mostly by themselves or a family member. Most of these growers reported using thresholds as well (Vandeman and others, 1994). Nearly 90 percent of the cotton acreage was scouted, including commercial scouting service on 40 percent of this acreage (table 4.4.1, fig. 4.4.1). Insect pests cause large economic losses in cotton production, and entomologists have been developing thresholds for these pests for several decades.

Figure 4.4.1--Use of scouting for pests, selected crops in major producing States, 1990's



Source: USDA, ERS, Cropping Practices and Chemical Use Surveys.

Application Tools. Producers use a variety of pesticide application techniques to make applications more efficient. For example, most farmers broadcast pesticides across the field, but an alternative technique--banding applications--can lower herbicide application rates substantially (Lin and others, 1995). However, mechanical cultivation to control weeds between rows is often required, and growers have not increased their use of banding during the 1990's. About 14 percent of the U.S. corn area in surveyed States treated with herbicides in 1994 was banded, and about 6 percent of soybeans were banded. Other examples of efficiency tools include drip pans for spray equipment to catch "overspray," and the use of dwarf fruit trees, which require less pesticide spray material than full-size trees.

Expert Systems. "Expert systems" integrate information on pest density, economic thresholds, application methods, and other elements of pesticide use into a computer software package that helps the farmer determine when to make pesticide applications, which pesticides to use, and how much to use. For example, a threshold-based model for corn and soybeans (NebraskaHERB) determines whether it is cost-effective to manage weeds in a

Table 4.4.4—Use of selected biological and cultural pest management practices on fruit, vegetable, and nut crops, major producing States, 1990's

Crop	In surveyed States[1]	Scouting: Consul-tants	Scouting: Grower/ family member	Scouting: Chem-ical dealer	Scouting: Other	Scouting: Total	Biological methods[2]: Benefi-cial insects	Biological methods[2]: Habitat provi-sion	Biological methods[2]: Phero-mone traps[3]	Biological methods[2]: Resist-ant varieties	Cultural methods[2]: Water manage-ment	Cultural methods[2]: Field sanita-tion	Cultural methods[2]: Adjust planting dates
	1,000 ac. planted	*Percent of acres*											
Fruit:													
Grapes, all	730	68	na	na	na	na	18	na	14	31	41	64	na
Oranges	613	75	na	na	na	na	22	na	28	21	27	48	na
Apples	381	54	na	na	na	na	2	na	66	16	22	73	na
All fruits & nuts	3,251	65	na	na	na	na	19	na	37	22	31	60	na
Vegetables:[4]													
Sweet corn	640	33	22	2	27	84	*	na	17	na	7	na	8
Tomatoes	357	5	15	47	1	68	5	na	6	na	21	na	47
Lettuce, head	259	32	26	26	9	93	3	na	1	na	4	na	26
All vegetables	2,914	21	19	19	15	74	3	na	7	na	11	na	15
	No. growers surveyed	*Percent of surveyed growers*											
Certified organic vegetables:													
Sweet corn	64	**	91	0	3	94	46	67	na	80	33	na	56
Tomatoes	55	**	94	0	1	95	48	57	na	71	46	na	41
Lettuce, head	33	**	97	0	3	100	60	60	na	73	80	na	50
All vegetables	303	**	91	0	6	97	46	58	na	75	44	na	54

* Used on less than 0.5 percent. **Included in other. na = not available.

[1] Data is from the 1991 USDA Chemical Use Survey for fruits and nuts, the 1992 Survey for vegetables, and the 1994 Survey for certified organic vegetables. For major producing States surveyed, see "Chemical Use Survey" in the appendix.

[2] Use for any type of pest in 1991 and 1992, and for three specific types (insects, disease, or weeds) in 1994 (highest use for a specific type is shown).

[3] Reported for all uses (pest control and monitoring) in 1991 and 1994, and for control only in 1992.

[4] Includes fresh and processing crops.

Source: USDA, ERS and NASS, Chemical Use Survey data.

field, and identifies whether broadcast or band-applied herbicides or cultivation is the most cost-effective treatment. The Nebraska Extension Service reports use in Nebraska is small but growing (USDA, 1994). The use of "expert systems" (decision support) software is still well under 1 percent in U.S. corn and soybean production according to recent ERS surveys (Padgitt, 1996). Several university expert systems, which forecast diseases in some major fruit and vegetable crops, have recently become available commercially through IPM product suppliers, including the "Penn State Apple Orchard Consultant" and the University of Wisconsin's WISDOM software.

Precision Farming. Precision farming is an emerging technology that may allow a more efficient application of inputs by using tractor-mounted yield monitors, satellite images, GIS, and other developing information technologies to tailor inputs to the different conditions in each field. Soil leachability, pH, and other characteristics often vary, sometimes substantially, within the farm field, and better tailoring of inputs to site-specific field conditions can increase crop yields. Most precision farming has addressed nutrient management, but research on pest management using this technology is emerging. Recent industry surveys indicate that only a small number of corn growers are experimenting with precision farming. The yield monitors and equipment necessary for many other crops, especially vegetable crops, have not been developed yet.

The potential for this technology to increase yields or to reduce pesticide use is being examined by USDA, the chemical industry, and other organizations. The few existing studies on the potential of precision farming to provide environmental benefits have been inconclusive about its effect on pesticide use.

Bioengineered Herbicide Tolerance. Seed and chemical companies have expanded research and development on plant biotechnology because of the increasing costs to develop chemical pesticides that meet human health and environmental regulations and are sufficiently toxic to kill target pests (Ollinger and Fernandez-Cornejo, 1995). Compared with traditional genetic plant breeding, plant biotechnology reduces the time required to identify desirable traits. In addition, by inserting into the plant a gene that imparts some desirable properties, biotechnology allows a precise alteration of a plant's traits, facilitating the development of plant characteristics not possible through traditional plant breeding techniques. This technology allows researchers to target a single plant trait, which decreases the number of unintended characteristics that may occur with traditional breeding techniques. The development of genetically modified plants takes about 6 years and costs about $10 million, while a chemical pesticide takes an average of 11 years at a cost of $50-$70 million to develop (Ollinger and Fernandez-Cornejo, 1995).

A number of seed and chemical companies have been developing plant varieties with resistance to particular herbicides (table 4.4.5). Monsanto has developed a soybean variety that is not damaged by Monsanto's popular herbicide glyphosate (Roundup) and similar glyphosate-tolerant varieties are being developed for canola, cotton, corn, sugar beets, and rapeseed oil. This technology could provide growers with an incentive to use pesticides that are effective at lower rates than other pesticides.

Concerns about this technology include the possibility of accelerated weed resistance as well as the toxicity of the herbicide products that crop tolerance is developed for. Danish scientists recently reported that the genes for herbicide resistance in transgenic oilseed rape had moved to field mustard, a wild relative, and that this weed demonstrated herbicide resistance (Kling, 1996).

Table 4.4.5—Bioengineered crop varieties approved for commercial production, 1994-96

Approval date[1]	Applicant	Crop
Herbicide-tolerant varieties:		
2/5/94	Calgene	Cotton
5/19/94	Monsanto	Soybean
6/22/95	AgrEvo	Corn
7/11/95	Monsanto	Cotton
12/19/95	Dekalb	Corn
1/26/96	Dupont	Cotton
7/31/96	AgrEvo	Soybean
Herbicide-tolerant varieties with other traits:		
2/22/96	Plant Genetic Systems	Corn[2]
(8/30/96)[3]	Monsanto	Corn[4]
Insect-resistant varieties:		
3/2/95	Monsanto	Potato
5/17/95	Ciba-Geigy	Corn
6/22/95	Monsanto	Cotton
8/22/95	Monsanto	Corn
1/18/96	Northrup-King	Corn
5/3/96	Monsanto	Potato
(8/14/96)[3]	Dekalb	Corn
Virus-resistant varieties:		
12/7/94	Upjohn	Squash
6/14/96	Asgrow	Squash
(2/20/96)[3]	Cornell University	Papaya

[1] Date the Animal Plant Health Inspection Service (APHIS) determined that these field-tested crop varieties had no potential for plant pest risk and need no longer be regulated.

[2] Includes a male sterility trait.

[3] Date APHIS received the petition for approval; non-regulated status is still pending.

[4] Includes an insect resistant trait.

Source: USDA, ERS, based on information provided by APHIS.

Biological Pest Management

According to a recent Office of Technology report, the market for biologically based pest controls is small but fast-growing. The market value of biologically based products—natural enemies, pheromones, and microbial pesticides—sold in the United States during the early 1990's was estimated at $95-$147 million, 1.3 to 2.4 percent of the total market for pest control products (U.S. Congress, 1995). At least 30 commercial firms or "insectaries" produce natural enemies. Even though the current market for biological products is growing and large pest control companies are beginning to participate, the market is still so small that biologicals are unlikely to replace pesticides in the foreseeable future unless major research and development activities are started (Ridgway and others, 1994).

Biological pest management includes the use of pheromones, plant regulators, and microbial organisms such as *Bacillus thuringiensis* (Bt), as well as pest predators, parasites, and other beneficial organisms. EPA currently regulates biochemicals and microbial organisms and classifies them as "biorational pesticides." Another major biological tactic has been to breed crop varieties with "host plant resistance" to insects and disease.

Microbial Pesticides and Pheromones. Biorational pesticides, such as Bt and pheromones, have differed significantly from chemical pesticides in that they have generally managed rather than eliminated pests, have had a delayed impact, and have been more selective (Ollinger and Fernandez-Cornejo, 1995). For example, microbial pesticides have not been successful as herbicides because target weeds are replaced by other weeds not affected by the microbial pesticide.

Among the most successful microbials has been Bt, which kills insects by lethal infection. Growers have dramatically increased their use of Bt during the 1990's, especially under biointensive and resistance-management programs, because of its environmental safety, improved performance, cost competitiveness, selectivity, and activity on insects that are resistant to chemical pesticides. It is one of the most important insect management tools in certified organic production. Bt was used on more than 1 percent of the acreage of 12 fruit crops in 1995, up from 5 crops in 1991 (table 4.4.6). Between 12 and 23 percent of the apple, plum, nectarine and blackberry acreage received Bt applications in 1995, and it was applied on over half of the raspberry acreage. Among vegetable crops, the acreage treated with Bt increased for 13 of the 20 crops surveyed by USDA between 1992 and 1994, and was used on about half or more of the cabbage, celery, and eggplant acreage. Bt has been used on only a couple of field crops. Corn acreage treated with Bt was steady at 1 percent in 1994 and 1995, while treated cotton increased from 5 percent in 1992 to 9 percent in 1994 and 1995.

New Bt strains with activity on insects not previously found to be susceptible to Bt have been discovered in recent years. Current research is devoted to improving the delivery of Bt to pests and to increasing the residual activity and efficacy of Bt.

Pheromones are used to monitor populations of crop pests and to disrupt mating in organic systems and some IPM programs. Pheromones were used on 37 percent of fruit and nut crops acreage to monitor and control pests and on 7 percent of vegetable acreage to control pests (use for monitoring was not included in this survey) (table 4.4.4).

Table 4.4.6—Agricultural applications of *Bacillus thuringiensis* (Bt), selected crops in surveyed States, 1991-95

Crop[1]	1994/95 planted acres[2]	Area receiving application				
		1991	1992	1993	1994	1995
	1,000 acres	*Percent of acres*				
Field crops:						
Corn (17 States)	64,105	*	*	*	1	1
Cotton, upland	11,650	*	5	8	9	9
Fruit:						
Grapes	796	*	-	2	-	6
Oranges	760	2	-	7	-	3
Apples, bearing	345	3	-	13	-	12
Peaches	144	*	-	3	-	5
Prunes	94	*	-	*	-	9
Pears	68	*	-	1	-	2
Sweet cherries	47	*	-	8	-	9
Plums	44	*	-	*	-	14
Nectarines	36	*	-	10	-	22
Blueberries	30	11	-	8	-	5
Raspberries	11	49	-	45	-	52
Blackberries	4	18	-	*	-	23
Vegetables:						
Tomatoes, proc.	323	-	6	-	5	-
Lettuce, head	191	-	18	-	20	-
Sweet corn, fresh	164	-	3	-	3	-
Onion	128	-	*	-	1	-
Broccoli	111	-	7	-	14	-
Tomatoes, fresh	104	-	31	-	39	-
Cantaloupe	98	-	32	-	8	-
Snap beans, fresh	71	-	20	-	29	-
Cabbage, fresh	70	-	48	-	64	-
Bell peppers	61	-	35	-	37	-
Lettuce, other	60	-	39	-	22	-
Cauliflower	54	-	12	-	20	-
Cucumbers, fresh	51	-	19	-	22	-
Strawberries	46	-	24	-	33	-
Celery	36	-	51	-	61	-
Honey dew	26	-	28	-	10	-
Spinach	10	-	13	-	21	-
Eggplant	4	-	13	-	48	-

* Applied on less than 0.5 percent of the acres. - = Not a survey year for that commodity.

[1] Bt use was too small to report on soybeans, wheat and potatoes, and on other surveyed fruit and vegetable crops.

[2] Planted acres in the surveyed States.The survey accounted for between 79 and 90 percent of U.S. total planted corn acreage, between 70 and 78 percent of the total Upland cotton acreage, and over 70 percent of fruit and vegetable acreage. For major producting States included, see "Chemical Use Survey" in the appendix.

Source: USDA, ERS and NASS, Chemical Use Survey data.

Beneficial Organisms. Natural enemies of crop pests, or "beneficials," may be imported, conserved, or augmented. Many crop pests are not native to this country, and USDA issues permits for the natural enemies of these pests to be imported from their country of origin. Natural enemy importation and establishment, also called classical biological control, has been undertaken primarily in university, State, and Federal projects; 28 States operate biocontrol programs and most have cooperative efforts with USDA agencies (U.S. Congress, 1995). Some crop pests, such as the woolly apple aphid in the Pacific Northwest, have been largely controlled with this method.

Natural enemies may also be "conserved" by ensuring that their needs—for alternate hosts, adult food resources, overwintering habitats, a constant food supply, and other ecological requirements—are met, and by preventing damage from pesticide applications and other cropping practices (Landis and Orr, 1996). Over half of the certified organic vegetable growers in 1994 were providing habitat for beneficials (table 4.4.4).

"Augmentation" boosts the abundance of natural enemies (native and imported) through mass production and inundative or inoculative releases in the field (Landis and Orr, 1996). An inundative release—the most common augmentation method—can be timed for when the pest is most vulnerable and is used when the natural enemy is absent or when its response to the pest pressure is insufficient. An inoculative release may be made in the spring for a natural enemy that cannot overwinter in order to establish a population. Unlike the importation and conservation approaches, the augmentation method generally does not provide permanent suppression of pests. Beneficial insects were used on 3 and 19 percent of the surveyed vegetable and fruit acreage in the early 1990's, and by nearly 46 percent of the certified organic vegetable growers (table 4.4.4).

A small but increasing number of companies are supplying natural enemies of insects, weeds, and other pests to farmers. For greenhouse and agricultural crop production, most natural enemies being sold—such as beneficial insects, predatory mites, parasitic nematodes, and insect egg parasites—are used for managing pest mites, caterpillars, citrus weevils, and other insect and arthropod pests. However, a number of natural enemies—musk thistle defoliating weevils, for example—are being sold for managing weeds on rangeland and uncultivated pastures (Poritz, 1996).

The California Environmental Protection Agency has published a list of commercial suppliers of natural enemies in North America since 1979, and the number has increased steadily. In 1994, 132 companies were listed, mostly in the United States, offering over 120 different organisms for sale (Hunter, 1994).

Host Plant Resistance. Corn and soybean breeding for genetic resistance to insects, disease, and other pests has been the research and development focus of major seed companies for many decades (Edwards and Ford, 1992). U.S. soybean acreage, for example, receives virtually no fungicides because of the effectiveness of the disease-resistance soybean cultivars that have been developed.

The use of classical breeding programs is now being augmented with new plant breeding efforts using transgenic and other genetic engineering techniques. In March 1995, the EPA approved, for the first time, a limited registration of genetically engineered plant pesticides to Ciba and Mycogen Plant Sciences, and in August 1995, granted conditional approval for full commercial use of a transgenic pesticide to combat the European corn borer (EPA, 1995). This plant pesticide, Bt corn, is produced when the genetic information related to insecticidal properties is transferred from the Bt bacterium to the corn plant. This technology could reduce the need for conventional chemical insecticides in corn production. In 1995, 26 percent of U.S. corn acreage was treated with insecticides (table 4.4.1), and corn borer is one of the top insect pests targeted for treatment.

However, since these new corn varieties contain natural genes and genes produced from the soil bacteria Bt, many scientists are concerned that the new corn will hasten pest immunity to Bt. This is especially a concern for the growing number of producers who rely on the foliar-applied Bt, and has led the EPA to approve the new pesticides conditional on the monitoring for pest resistance and the development of a management plan in case the insects become resistant.

The techniques used for developing disease-resistant plants are similar to the immunization of humans by vaccines. Small amounts of plant viruses are inserted into the plants, which subsequently become immune to the diseases (Salquist, 1994). The plants are capable of passing this trait from generation to generation. For example, researchers have developed squash varieties that are naturally virus-resistant, thus preventing insect-borne viruses that can destroy up to 80 percent of the squash crop. A number of seed and chemical companies and one university have been field-testing insect- and virus-resistant plants, developed with these genetic engineering techniques, for several major field crops and vegetables (table 4.4.5).

While most classical breeding programs have focused on pests resistant to chemicals or treatments that were too expensive (Zalom and Fry, 1992b), consumer concern over pesticides in agricultural products has prompted biotechnology companies to enter the genetically engineered plant market. As agricultural biotechnology products attain commercial success, some private investment funding may shift from the smaller pharmaceutical markets toward agricultural crop protection (Niebling, 1995). On the other hand, consumer acceptance of the bioengineered Bt corn, Bt cotton, and other genetically engineered crops has not yet been demonstrated in major U.S. markets. A 1992 survey of U.S. consumer attitudes about food biotechnology, published by North Carolina State University, found that most consumers want information on labels about various food characteristics, including the use of biotechnology (Hoban and Kendall, 1993).

APHIS (Animal Plant Health Inspection Service) has approved or acknowledged 638 field trials for insect-resistant varieties since 1987 (24 percent of the total field trials approved or acknowledged), 286 field trials to test viral resistance (11 percent), and 94 field trials for fungal resistance (3.5 percent).

Cultural Pest Management

A number of production techniques and practices—including crop rotation, tillage, alterations in planting and harvesting dates, trap crops, sanitation procedures, irrigation techniques, fertilization, physical barriers, border sprays, cold air treatments, and habitat provision for natural enemies of crop pests—can be used for managing crop pests. Cultural controls work by preventing pest colonization of the crop, reducing pest populations, reducing crop injury, and enhancing the number of natural enemies in the cropping system (Ferro, 1966).

These ecosysem-based pest control techniques are knowledge-intensive, and widespread adoption by growers would require major new funding for basic and applied research (National Academy of Sciences). The National Research Council also suggests that the base of research necessary to develop and implement cultural pest management and other ecosystem-based pest management techniques is much greater than for synthetic chemical pesticides.

Crop rotation is one of the most important of the current cultural techniques. Eighty percent of U.S. corn acreage was in rotation with other crops in 1995, up slightly from 76 percent in 1990 (table 4.4.1). Over half of the corn was being grown in rotation with soybeans and about 15 percent with other row crops (see chapter 4.3, *Cropping Management*, for more detail on cropping patterns). Ninety percent of soybeans were grown in crop rotations in 1995. Corn producers rotating corn with other crops used insecticides less frequently than did those planting corn 2 years in succession (11 percent of acres versus 46 percent). Corn is often grown as a monocrop in heavy livestock areas and where climate limits the soybean harvest period (Edwards and Ford, 1992).

Crop rotation was much less prevalent for cotton, which has among the highest per-acre returns of U.S. field crops. Less than one-third of the cotton producers use this technique (table 4.4.1). Crop rotation in wheat varies with the type being grown; it was used on 77 percent of the spring crop but only 57 percent of the winter wheat crop in 1995. Crop rotation was used for virtually all of the potato acreage.

Cultivation for weed control is widely practiced for field crops, mostly in conjunction with herbicide use. Almost all of the potato and cotton acreage received cultivations in 1995, along with 66 percent of corn. For soybeans, cultivations dropped from 67 percent in 1990 to 41 percent in 1995 (table 4.4.1).

Field sanitation and water management (see glossary) are widely used on fruit and nut crops, with 60 percent and 31 percent of the acreage under these practices in the early 1990's (table 4.4.4). For vegetable crops, planting dates were adjusted as a cultural control on 15 percent of the surveyed crop area. Water management was used by 44 percent of the certified organic vegetable producers, and over half were using adjusted planting dates to manage pests.

Research on new cultural techniques such as solarization—heating the soil to kill crop pests—continues to emerge. However, most cultural practices do not involve a marketable product, and research and development depends almost entirely on public sector funding (U.S. Congress, 1995). While cultural practices may be effective for controlling pests, reducing pesticide use, and lowering input costs, these techniques require a knowledgeable producer and growers may not be getting adequate information about them.

Pest Management Programs and Initiatives

Pest management systems in the future will emerge against the backdrop of continued consumer preference for fewer farm chemicals and scientific uncertainty about the ecological and health impacts of chemical use. In addition to State and Federal pesticide regulations, farmers' pest management choices will be influenced by the costs and risks of pesticides and alternatives, the market for green products, and other factors. USDA, EPA, and other government agencies have initiated a number of programs to encourage biological and cultural pest management, including biointensive IPM research and promotion, areawide pest management, regulatory streamlining for biologicals, and national organic standards development.

IPM Research and Promotion

On September 22, 1993, the EPA, USDA, and the Food and Drug Administration (FDA) presented joint testimony to Congress on a comprehensive interagency effort designed to reduce the pesticide risks associated with agriculture. The three goals of this effort are to (1) discourage the use of higher risk products, (2) provide incentives for the development and commercialization of safer products, and (3) encourage the use of alternative control methods which decrease the reliance on toxic and persistent chemicals (Browner and others, 1993). This joint testimony also expressed support for integrated pest management (with a goal of IPM programs on 75 percent of total U.S. crop acreage by the year 2000), ecosystem-based programs to reduce pesticide use, market-based incentives such as reduced-pesticide use food labels, and other efforts to help reduce pesticide risks.

State Extension Service IPM programs are overseen by designated IPM coordinators, mostly entomologists who focus on developing interdisciplinary pest management programs (Grey, 1995). Over half of U.S. farmers are using a minimum level of IPM—including scouting for insect pests and applying insecticides when economic thresholds are reached (Vandeman and others, 1994)—as opposed to the conventional pesticide application method of preventative, calendar-based spraying. Economic and environmental studies have reported mixed results in terms of the impacts of IPM scouting and thresholds on pesticide use (Rajotte and others, 1987; Mullen, 1995; and Ferguson and Yee, 1995; Fernandez-Cornejo, 1996).

The first national study of biologically based IPM in the early 1990's, jointly sponsored by USDA and EPA, concluded that dozens of technical, institutional, regulatory, economic, and other constraints need addressing in order to achieve broader adoption (Zalom and Fry, 1992a). Three constraints were identified by all commodity groups: (1) lack of funding and personnel to conduct site-specific research and demonstrations; (2) producer perception that IPM is riskier than conventional methods, more expensive, and not a shortrun solution; and (3) educational degree programs that are structured toward narrow expertise rather than broad knowledge of cropping systems (Glass, 1992).

The current IPM initiative in USDA, which has been partly funded by Congress, attempts to address the funding constraint and need for demonstrations and highlights stakeholder involvement in priority setting for IPM research (Jacobsen, 1996). A few IPM research projects have started to examine biocontrols and cultural practices for several commodities, especially those that may not have adequate pest management alternatives because of current or pending EPA regulatory actions or voluntary pesticide registration cancellations.

Areawide Pest Management Systems

USDA is also developing and implementing an areawide pest management approach—through partnerships with growers, commodity groups, government agencies, and others—to contain or suppress the population levels of major insect pests in agriculture over large definable areas, as opposed to on a farm-to-farm basis (Calkins and others, 1996). Biological and cultural methods are the focus of most of these areawide programs.

Some biological control tactics, such as sterile insect releases, are most effective if implemented on a large area that encompasses many farms (U.S. Congress, 1995). For example, corn rootworm is a highly mobile pest as an adult and management is expected to be more effective over a large area. The goals of the program are to provide more sustainable pest control, at costs competitive with insecticide-based programs, and to reduce the use of chemical insecticides in agriculture. One successful biologically based areawide program was launched against the screwworm, a major parasitic pest of livestock, pets, and humans. USDA began releasing sterile male screwworm flies into wild populations in the 1950's, and by the early 1980's the screwworm became the only pest successfully eradicated from the United States (U.S. Congress, 1995).

USDA currently has five biologically based areawide IPM projects in various stages of evaluation, pilot testing, and large area implementation (table 4.4.7). The oldest, the Areawide Bollworm/Budworm Project in Mississippi, was initiated in 1987. Under this project, serious insect pests of Delta crops, especially cotton, were managed successfully with natural insect pathogens in small field tests. The project went into a large-area testing phase with 215,000 acres in 1994 and 1995.

Another areawide IPM project, the regional Coddling Moth Areawide Management Program (CAMP), uses pheromone mating disruption to control the coddling moth, the primary insect pest of apples in California, Oregon, and Washington. CAMP is a cooperative effort between ARS and three universities, and it aims to reduce organophosphate insecticide use by 80 percent in these apple- and pear-producing States (Kogan, 1996). The coddling moth had grown resistant to the organophosphate insecticide which required growers to triple applications of that chemical (Flint and Doane, 1996). Pilot testing of the project began in 1995 on five sites, and initial results indicate substantial reductions in organophosphate use and a positive response from growers (Kogan, 1996).

Two projects are examining the areawide use of attractants—semiochemical bait with tiny amounts of insecticide—to control corn rootworm in the Midwest, and Mexican corn rootworm and cotton bollworn in Texas and other States (Calkins and others, 1996). The Federal Crop Insurance Corporation has issued a crop insurance endorsement to cover any crop losses that might occur in testing sites.

Regulatory Streamlining for Alternatives

The EPA has facilitated the development of biorational pesticides by establishing a tier approval system in which, under some circumstances, several tests are waived. These reduced regulation costs have helped lower the development costs of biopesticides, which are currently estimated at around $5 million per product, compared with about $50-$70 million for a chemical pesticide (Ollinger and Fernandez-Cornejo, 1995).

The EPA is also making the regulation of biorational pesticides less stringent than that of chemical pesticides. For example, Lepidopteran pheromones may now be used experimentally on up to 250 acres without an experimental-use permit and are exempted from a food tolerance measure (*Pesticides & Toxic Chemical News*).

The EPA has also facilitated the use of minimum-risk alternatives to toxic pesticides by establishing a process for exemption from costly FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) requirements. Thirty-one substances (see box) deemed to pose insignificant risks to human health and the environment have recently been deregulated. EPA considered whether the substances were common foods, had a nontoxic mode of action, had FDA recognition as safe, had no information showing significant adverse effects, persistence in the environment and other factors. Supporters of the draft proposal on exemptions felt that deregulation of these substances would particularly benefit small businesses and the organic industry and supported the expansion of this list in the future, while opponents were concerned about product effectiveness (U.S. EPA, 1996a).

National Organic Standards, Certification, and Ecolabels

Organic farming systems focus on biological and cultural methods for pest management and virtually exclude the use of synthetic chemicals. In 1990, Congress passed the Organic Foods Production Act to provide consistent national standards to consumers for

Deregulated Minimum-Risk Pesticides

The following minimum-risk pesticides, mostly from common food substances, were exempted from costly Federal Insecticide, Fungicide, and Rodenticide Act requirements by the U.S. Environmental Protection Agency in a 1996 ruling: castor oil (U.S.P. or equivalent), cedar oil, cinnamon and cinnamon oil, citric acid, citronella and its oil, cloves and clove oil, corn gluten meal, corn oil, cottonseed oil, dried blood, eugenol, garlic and garlic oil, geraniol, geranium oil, lauryl sulfate, lemongrass oil, linseed oil, malic acid, mint and mint oil, peppermint and peppermint oil, 2-phenethyl propionate (2-phenylethyl propionate), potassium sorbate, putrescent whole egg solids, rosemary and rosemary oil, sesame and sesame oil, sodium chloride (common salt), sodium lauryl sulfate, soybean oil, thyme and thyme oil, white pepper, and zinc metal strips.

Source: EPA, 1996a.

Table 4.4.7—Implementation status of USDA's biologically-based areawide projects[1]

Project and objectives	Methods	Extent of implementation	Preliminary results
Coddling Moth, Pacific Northwest (Apples, pears) *Objective* - reduce broad spectrum neurotoxic insecticide use and maintain yields	Mating disruption Resistant cultivars Sanitation Natural enemies Early season Bt Sterile males	1995-1996: Randall Island, CA Medford, OR Yakima, WA Howard Flats, WA Orovill, WA 1997 planned: 5 additional sites	Late-season pesticide use declined Natural enemies increased Secondary pests declined Fruit damage was below 0.1% economic threshold 1st generation moths were reduced 80% Input costs were higher
Western Corn Rootworm Northern Corn Rootworm, Midwestern U.S. (Corn) *Objective* - reduce insecticide use and area treated, maintain yields, and reduce pest populations	Monitoring Semiochemical traps Semiochemical bait (includes tiny amounts of carbaryl)	1996: Brookings, SD 1997 planned: Illinois and Indiana Iowa Kansas	90% or more of the adults were killed (below threshold level) Natural enemies increased
Mexican Corn Rootworm, Texas & Oklahoma (Corn) *Objective* - reduce insecticide use and area treated; maintain or increase yields	Monitoring Semiochemical traps Semiochemical bait (includes tiny amounts of carbaryl)	1996: Bell County, TX 1997 planned: Bell County, TX	Adult population reduced below threshold levels; larvae will be assessed next spring No impact on beneficials Increased management costs offset by decreased input costs
Cotton Bollworm & Tobacco Budworm, Mississippi (Cotton) *Objective* - reduce insecticide use and area treated, maintain yields, and reduce pest populations	Monitoring with pheromone traps Insect virus (Gemstar) used on early-season weed hosts	1990-93: Mississippi (0-64,000 acres)[2] 1994-95: Mississippi (215,000 acres) 1996: Mississippi (25,000 acres) 1997 planned: Mississippi (215,000 acres) 1998 planned: Mississippi (850,000 acres)	More than 70% of moths killed Reduced insecticide use Yields were maintained Input and management costs were lowered

[1] USDA's Agricultural Research Service (ARS) is administering these projects through partnerships with other Federal agencies, universities, commodity associations, and other stakeholder groups.

[2] Pilot test acreage varied due to changes in funding and experiment design, and testing was cancelled one year because of severe flooding.

Source: USDA, ERS, based on Calkins and others, 1996; Kogan, 1994; and personal communication with Carrol Calkins, USDA-ARS, Yakima, WA, Laurence Chandler, USDA-ARS, Brookings, South Dakota; James Coppedge, USDA-ARS, College Station, Texas, and Dick Hardee, USDA-ARS, Stoneville, Mississippi.

organic production and processing methods. This legislation requires that all except the smallest organic growers be certified by a State or private agency accredited under national standards currently being developed.

The National Organic Standards Board, which was appointed by USDA to help implement the Act, currently defines organic agriculture as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimum use of off-farm production inputs, on management practices that restore and enhance ecological harmony, and on practices that maintain organic integrity through processing and distribution to the consumer" (Ricker, 1996). USDA is expected to publish the draft national organic standards in the Federal Register in 1997.

Organic Production. National data indicate a growing organic niche in the U.S. farm sector. A recent survey of public and private organic certifications indicated that there were at least 4,050 certified organic farms in the United States in 1994 with over a million acres in organic production (Dunn, 1995). And these statistics underestimate the number of U.S. growers using organic production methods, since the growers must farm organically for at least 3 years before they can certify their production under most certification organizations.

About 1 percent of the total U.S. fruit and vegetable acreage is organic, a higher proportion than for field crops, livestock feed, cotton, and other commodity sectors. California, the largest fruit and vegetable producing State, reports that organic farmers account for about 2 percent of its 80,000 farmers (White, 1994).

Few case studies have examined yields, input costs, income, and other characteristics of organic production. A review of the economic literature published in the 1970's and 1980's concluded that the "variation within organic and conventional farming systems is likely as large as the differences between the two systems," and found mixed results in the comparisons for most characteristics (Knoblauch, Brown, and Braster, 1990). Organic price premiums are key in giving organic farming systems comparable or higher whole-farm profits than conventional systems (Klonsky and Livingston, 1994; Batte, Forster, and Hitzhusen, 1993).

Organic agriculture is the most thoroughly documented system of ecological pest management in the United States. At least 11 States and 33 private agencies in the United States offer certification services to organic growers to ensure they are using the ecologically based standards associated with organic farming systems. California Certified Organic Farmers is a private certification organization and the oldest certifier in the Nation.

Certified Organic Labels. Over half the States have laws that regulate the production and marketing of organic food, and about half the States require State or private certification of products and operations to ensure that they are using only approved materials and practices. National standards under development in USDA are expected to facilitate international trade as well as enhance consumer confidence in organic food commodities.

Organic food products account for only about 1 percent of total retail food sales, but organics are one of the fastest growing segments of the industry. Consumer demand for organic food products has increased throughout the 1990's. Retail sales of fresh and processed organic food products reached $2.8 billion in 1995, and have increased over 20 percent annually since 1989 (*Natural Foods Merchandiser*, 1996). Increases in the number of large-format natural food stores, supermarket organic sections, export markets and direct-marketing outlets, as well as the expanding variety of organic foods, have fueled this growth. Organic products are labeled at retail in a variety of ways, including stickers, labels, signs, and other methods that indicate the certification organization or give other information.

Voluntary Environmental Standards. In addition to stronger pesticide regulations over the last decade, voluntary codes for environmental stewardship and responsible pesticide use in agriculture have begun to emerge. These codes are instituted by the private sector, enforced by firms themselves, use sanctions such as peer pressure for compliance, focus on life-cycle impacts, emphasize management systems, and let firms define their own performance standards. They can shift some of the environmental management costs to the private sector, expand a firm's environmental focus beyond the scope of regulation, help a firm integrate environmental and business objectives, and foster long-term changes in a firm's environmental consciousness (Nash and Ehrenfeld, 1996).

The Pesticide Environmental Stewardship Program was initiated in 1992 by EPA, USDA, and FDA to facilitate this type of voluntary approach, inviting organizations that use pesticides or represent pesticide users to join as partners (U.S. EPA, 1996b). Partners agree to implement formal strategies to reduce the use and risk of pesticides and to report regularly on progress. Membership in this stewardship program has grown to 41 partners, including many commodity groups across the country, and represents at least 45,000 pesticide users. The California Department of Agriculture has established a similar program, the IPM Innovators Program, to recognize individuals and groups that have demonstrated leadership in voluntarily implemented systems that reduce pesticide risks (Brattesani and Elliott, 1996) and to raise the environmental consciousness of other groups that use pesticides and inspire them to voluntarily adopt similar activities. Also, some States are examining the potential benefits of IPM certification, while Massachusetts is already operating a "Partners with

GLOSSARY

Chemical Methods

Banded pesticide application—the spreading of pesticides (herbicides, insecticides, or fungicides) over, or next to, each row of plants in a fields. Banding herbicides often requires row cultivation to control weeds in the row middles.

Broadcast pesticide application—the spreading of pesticides (herbicides, insecticides, or fungicides) over the entire surface area of the field.

Economic thresholds—levels of pest population which, if left untreated, would result in reductions in revenue that exceed treatment costs. The use of economic thresholds in making pesticide treatment decisions requires information on pest infestation levels from scouting.

Pesticides—the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) defines a pesticide as "any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant."

Pre-emergence herbicide—herbicides which are applied before weeds emerge. Pre-emergence herbicides have been the foundation of row-crop weed control for the past 30 years.

Post-emergence herbicides—herbicides which are applied after weeds emerge. Post-emergence herbicides are considered more environmentally sound than pre-emergence herbicides because they have little or no soil residual activity.

Scouting—checking a field for the presence, population levels, activity, size, and/or density of weeds, insects, or diseases. A variety of methods can be used to scout a field. Insect pests, for example, can be scouted by using sweep nets, leaf counts, plant counts, soil samples, and general observation.

Cultural Methods

Crop rotation—alternating the crops grown in a field on an annual basis, which interrupts the life cycle of insect pests by placing them in a non-host habitat.

Planting and harvesting dates—alterations in planting date and harvest date to avoid damaging pest infestations. Delayed planting of fall wheat seedlings may help avoid damage from the Hessian fly, for example.

Sanitation procedures—removing or destroying crops and plant material that are diseased, provides overwintering pest habitat, or encourages pest problems in other ways.

Tillage—can destroy pests in a variety of ways, for example, by directly destroying weeds and volunteer crop plants in and around the field.

Water management—water can be used as a pest management technique either directly, by suffocating insects, or indirectly, by changing the overall health of the plant.

Biological Methods

Beneficials—organisms that are pest predators and parasites and weed-feeding invertebrates that are used to control crop pests and weeds.

Habitat provision for natural enemies—growing crops and/or developing wild vegetative habitats to provide food (pollen, nectar, non-pest arthropods) and shelter for the natural enemies of crop pests.

Biochemical agents—include semiochemicals, plant regulators, hormones, and enzymes.

***Bacillus thuringiensis*, Bt**— bacteria that is used to control numerous larva, caterpillar, and insect pests in agriculture; *Bacillus thuringiensis* varieties *kurstaki* and *Bacillus thuringiensis* varieties *aizawai* are commonly used strains. In addition, some new varieties of corn contain natural genes and genes produced from the soil bacteria Bt to give them host-plant resistance to certain insect pests.

Gemstar— naturally occuring *Helicoverpa zea* nuclear polyhedrosis virus.

Microbial pest control agents—bacteria, such as *Bacillus thuringiensis*, viruses, fungi, and protozoa and other microorganisms or their byproducts.

Semiochemicals—pheromones, allomones, kairomones, and other naturally or synthetically produced substances that modify insect behavior.

Trap cropping—planting a small plot of a crop earlier than the rest of the crop in order to attract a particular crop pest; the pests are then killed before they attack the rest of the crop.

Sterile male technology—the male of the pest species is produced with inactive or no sperm, and is used to disrupt reproduction in the pest population.

Nature" program to recognize growers who follow a set of IPM certification guidelines (Van Zee, 1992).

Author: Catherine Greene, (202) 219-0466 [cgreene@econ.ag.gov]. Contributors: Jorge Fernandez-Cornejo, Merritt Padgitt, Sharon Jans, and Sarah Lynch.

References

Alavanja, M.C.R., A. Blair, S.B. McMaster, and D.P. Sandler (1993). "Agricultural Health Study: A Prospective Study of Cancer and Other Diseases Among Men and Women in Agriculture," National Cancer Institute, U.S. Environmental Protection Agency, and the National Institute of Environmental Health Sciences, Oct. 25 (Revisions Dec. 16).

Alavanja, Michael C. R., Dale P. Sandler, Suzanne B. McMaster, Shelia Hoar Zahm, Cheryl J. McDonnell, Charles F. Lynch, Margaret Pennybaker, Nathaniel Rothman, Mustafa Dosemeci, Andrew E. Bond, and Aaron Blair (1996). "The Agricultural Health Study," *Environmental Health Perspectives*, 104: 362-369.

AgriSystems International (1996). *International Organic Markets Report 1996*. Agrisystems International, Wind Gap, PA.

Arnold, Steven F., Diane M. Klotz, Bridgette M. Collins, Peter M. Vonier, Louis J. Guillette Jr., and John A. McLachlan (1996). "Synergistic Activation of Estrogen Receptor With Combinations of Environmental Chemicals," *Science*, Vol. 272, June 7.

Batte, Marvin T., D. Lynn Forster, and Fred J. Hitzhusen (1993). "Organic Agriculture in Ohio: An Economic Perspective," *Journal Production Agricultur*e, Vol. 6, No. 4.

Brattesani, Madeline, and Robert Elliott (1996). "The IPM Innovators Program," California Environmental Protection Agency, Department of Pesticide Regulation, Jan. 25.

Browner, Carol M., Administrator, U.S. Environmental Protection Agency; Richard Rominger, Deputy Secretary, U.S. Department of Agriculture; and David A. Kessler, Commissioner, Food and Drug Administration (1993). "Testimony before the Subcommittee on Department Operations and Nutrition Committee on Agriculture," U.S. House of Representatives, Sept. 22.

Buchman, Stephen L., and Gary P. Nabhan (1996). *The Forgotten Pollinators*. Washington, DC: Island Press/Shearwater Books.

Calkins, C. O., R. M. Faust, J. R. Coppedge, J. F. Brunner, L. D. Chandler, D. D. Hardee, and M. R. Bell (1996). *Areawide IPM as a Tool for the Future*, USDA, Agricultural Research Service, speech presented at the Third National IPM Workshop/Symposium, Feb.-March.

Cate, J.R., and M.K Hinkle (1994). *Integrated Pest Management: The Path of a Paradigm*. National Audubon Society, Alexandria, VA: Weadon Printing.

Coble, Harold D., and David A. Mortensen (1992). "The Threshold Concept and its Application to Weed Science," *Weed Technology*, Vol. 6, No. 1.

Dunn, Julie Anton (1995). *Organic Food and Fiber: An Analysis of 1994 Certified Production in the United States*, U.S. Department of Agriculture, Agricultural Marketing Service, Transportation and Marketing Division, Sept.

Edwards, C. Richard, and Richard E. Ford (1992). "Integrated Pest Management in the Corn/Soybean Agroecosystem," *Food, Crop Pests, and the Environment* (F. G. Zalom and W. E. Fry, ed.). The American Phytopathological Society, St. Paul, MN: APS Press.

Ferguson, Walter, and Jet Yee (1995). "A Logit Model of Cotton Producer Participation in Professional Scout Programs," *Journal of Sustainable Agriculture*, Vol. 5, No. 3.

Fernandez-Cornejo, Jorge (1996). "The Microeconomic Impact of IPM Technology," *Agricultural and Resource Economics Review*, Oct.

Ferro, David N. (1996). "Cultural Controls, Electronic IPM Textbook," (E. B. Radcliffe and W. D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Flint and Doane (1996). "Pheromones and Other Semiochemicals," Electronic IPM Textbook, (E. B. Radcliffe and W. D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (http://www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Glass, Edward H. (1992). "Constraints to the Implementation and Adoption of IPM," *Food, Crop Pests, and the Environment* (F. G. Zalom and W. E. Fry, ed.), American Phytopathological Society, St. Paul, MN: APS Press.

Gray, Michael E. (1995). "Status of CES-IPM Programs: Results of a National IPM Coordinators Survey," *American Entomologist*, Vol. 41, No. 3.

Hoban, Thomas J, and Patricia A. Kendall (1993). "Consumer Attitutes About Food Technology: Project Summary." U.S. Dept. Agr., Extension Service, North

Carolina State Univ. and Colorado State Univ., Project No. 91-EXCA-3-0155.

Hunter, Charles D. (1994). *Suppliers of Beneficial Organisms in North America*, PM 94-03, California Environmental Protection Agency, Department of Pesticide Regulation.

Jacobsen, Barry (1996). "USDA Integrated Pest Management Initiative," Electronic IPM Textbook, (E. B. Radcliffe and W. D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (http://www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Klassan, Waldemar, and Paul Schwartz, Jr. (19__). "ARS Research Program in Chemical Insect Control," *Agricultural Chemicals of the Future*, BARC Symposium 8 (James L. Hilton, ed.), Rowman & Allanheld, Totowa.

Kling, James (1996). "Could Transgenic Supercrops One Day Bred Superweeds?" *Science*, Vol. 274, Oct. 11.

Klonsky, Karen, and Peter Livingston (1994). "Alternative Systems Aim to Reduce Inputs, Maintain Profits," *California Agriculture,* Vol. 48, No. 5.

Knoblauch, Wayne A., Rebecca Brown, and Martin Braster (1990). "Organic Field Crop Production: A Review of the Economic Literature," A.E. Res. 90-10, Department of Agricultural Economics, Cornell University Agricultural. Experiment Station, Cornell University, Ithaca, NY, July.

Kogan, Marcos (1996). "Areawide Codling Moth Management," *IPM in the Western Region*, Sorrel Brown (ed.), NCR Educational Materials Project, Iowa State University.

Kogan, Marcos, ed. (1994). "Areawide Management of the Codling Moth: Implementation of a Comprehensive IPM Program for Pome Fruit Crops in the Western U.S.," Integrated Plant Protection Center, Oregon State University, July.

Landis, Douglas A., and David B. Orr (1996). "Biological Control: Approaches and Applications," Electronic IPM Textbook, (E.B. Radcliffe and W.D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (http://www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Lin, Biing-Hwan, Harold Taylor, Herman Delvo, and Len Bull (1995). "Factors Influencing Herbicide Use in Corn Production in the North Central Region," *Review of Agricultural Economics*, Vol. 17, No. 2.

Litovitz, T. L., B. F. Schmitz, and K. M. Bailey (1990). "1989 Annual Report of the American Association of Poison Control Centers National Data Collection System," *American Journal Emerging Medicine,* Vol. 8, pp. 394-442.

MacIntyre, Angus A. (1987). "Why Pesticides Received Extensive Use in America: A Political Economy of Agricultural Pest Management to 1970," *Natural Resources Journal*, Vol. 27, Summer.

Mullen, Jeffrey (1995). "Estimating Environmental and Human Health Benefits of Reducing Pesticide Use Through Integrated Pest Management Programs," M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, Aug.

Nash, Jennifer, and John Ehrenfeld (1996). "Code Green: Business Adopts Voluntary Environmental Standards," *Environment*, Vol. 38, No. 1.

National Academy of Sciences (1995). *Ecologically Based Pest Management: New Solutions for a New Century.* National Research Council, Board on Agriculture, Washington, DC: National Academy Press.

Natural Foods Merchandiser (1996). "Widening Market Carries Organic Sales to $2.8 Billion in 1995," *Natural Foods Merchandiser*, Vol. XVII, No. 6. New Hope Communications.

Niebling, Kenneth (1995). "Agricultural Biotechnology Companies Set Their Sights on Multi-Billion $$ Markets," *Genetic Engineering News*, July.

Ollinger, Michael, and Jorge Fernandez-Cornejo (1995). *Regulation, Innovation and Market Structure in the U.S. Pesticide Industry*, USDA, Economic Research Service, AER-719, June.

Orzalli, Rick, Bob Curtis, and Hasan Bolkan (1996). "Implementing IPM Programs, Keys to Success: Campbell Soup Company," speech presented at the Third national IPM Workshop/Symposium, Feb.-March.

Osteen, Craig (1987). "The Policy and Economic Issues of Pest Control and Energy Use," Zane R. Helsel (ed.), E*nergy in World Agriculture*, Elsevier Press.

Osteen, Craig, and Philip Szmedra (1989). *Agricultural Pesticide Use Trends and Policy Issues*, USDA, Economic Research Service, AER-622, Sept.

Padgitt, Merritt (1996). "Cropping Practices Survey, 1990-1995 Summary: Pesticide Use and Application Practices," USDA, Economic Research Service, unpublished statistical summary, May 6.

Pease, William S., James Liebman, Dan Landy, and David Albright (1966). "Pesticide Use in California: Strategies for Reducing Environmental Health Impacts." California Policy Seminar, University of California, Berkeley, Center for Occupational and Environmental Health.

Pimentel, David, H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, and M. D'Amore (1992). "Environmental and Economic Costs of Pesticide Use," *BioScience*, Vol. 42, No. 10.

Poritz, Noah (1996). "Biological Control of Weeds: An Alternative," *Biological Control of Weeds 1996*, Bozeman, MT.

Public Law: 104-170, 104th Congress (1966). Food Quality Protection Act, EPA, Prevention, Pesticides and Toxic Substances, 7501W, Nov.

Rajotte, Edwin G., Richard F. Kazmierczak, Jr., George W. Norton, Michael T. Lambur, and William A. Allen (1987). *The National Evaluation of Extension's Integrated Pest Management (IPM) Programs*, Virginia Cooperative Extension Service Publication 491-010, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Ricker, Harold S. (1996). "The National Organic Program - Status and Issues," Third National IPM Symposium/Workshop: A Proceedings," USDA, Economic Research Service, forthcoming.

Ridgway, R. L., M. N. Inscoe, and K. W. Thorpe (1994). "Biologically Based Pest Controls: Markets, Industries, and Products," Special Report for OTA, Beltsville Agricultural Research Center, USDA, Agricultural Research Service, May 20.

Salquist, T. (1994). "Dawn of Genetic Engineering," *Farm Chemicals*, Sept.

Schwartz, P.H., and W. Klassen (1991). "Current Crop Losses to Pests Despite the Use of Pesticides and Other Controls," Unpublished manuscript.

U.S. Department of Agriculture (1994). *IPM The Annual Report: State Accomplishments 1993*, USDA, Cooperative Extension System.

U.S. Environmental Protection Agency (1997). "Questions & Answers: Potential of Chemicals to Affect the Endocrine System," *Prevention, Pesticides and Toxic Substances* (7506C), Jan. 30.

______________________________ , (1996a). "Exemption of Certain Pesticide Substances From Federal Insecticide, Fungicide, and Rodenticide Act Requirements," Federal Register, Vol. 61, No. 45.

______________________________ , (1996b). "Partnerships in Preventing Pollution: A Catalogue of the Agency's Partnership Programs," EPA 100-B-96-001, Office of the Administrator, Spring.

______________________________, (1995). "EPA Issues Conditional Approval for Full Commercial Use of Field Corn Plant Pesticide Targeting the European Corn Borer," EPA Press Release, Aug. 11.

______________________________, (1987). *Unfinished Business: A Comparative Assessment of Environmental Problems*. Vol. 1 Overview, Feb.

U.S. Congress, Office of Technology Assessment (1995). *Biologically Based Technologies for Pest Control*, OTA-ENV-636, Washington, DC: Government Printing Office.

Vandeman, Ann, Jorge Fernandez-Cornejo, Sharon Jans, and Biing-Hwan Lin (1994). *Adoption of Integrated Pest Management in U.S. Agriculture*, AIB-707, USDA, Economic Research Service, Sept.

Van Zee, Vicki (1992). "Partners with Nature: A Massachusetts Integrated Pest Management Recognition Program," *Fruit Notes*, Vol. 57, No. 4, Massachusetts Department of Food and Agriculture.

White, Janet (1994). "Farming in Transition: Editor's Note," *California Agriculture*, Vol. 48, No. 5.

Zalom, F. G., and W. E. Fry (1992a). *Food, Crop Pests, and the Environment*, American Phytopathological Society, St. Paul, MN: APS Press.

Zalom, F. G., and W. E. Fry (1992b). "Biologically Intensive IPM for Vegetable Crops," *Food, Crop Pests, and the Environment*, American Phytopathological Society, St. Paul, MN: APS Press.

Recent ERS Research on Pest Management Issues

Proceedings of the Third National IPM Symposium/Workshop: Broadening Support for 21st Century IPM, May 1997, Miscellaneous Publication Number 1542 (Sarah Lynch, Cathy Greene, and Carol Kramer-LeBlanc, editors). IPM program assessment was a major focus of the interdisciplinary IPM symposium/workshop held last winter in Washington DC. Several papers in this proceedings explore ways to incorporate the economic, environmental, and public health impacts of IPM programs into research and extension activities.

"Organically Grown Vegetables: U.S. Acreage and Markets Expand during the 1990's," April 1997, VGS-271, *Vegetables and Specialties: Situation and Outlook Report* (Catherine Greene and Linda Calvin). Organic farming systems, which focus on ecologically-sound production practices, have been gaining ground among U.S. vegetable growers during much of the 1990's. Organic vegetables are currently being grown and certified by State and private agencies on about 1 percent of U.S. vegetable acreage—ranging from 0.2 percent to over 10 percent in top vegetable States—and implementation of national standards is expected to facilitate the use of these systems.

Pest Management on Major Field Crops, AREI Updates, No. 1, February 1997 (Merritt Padgitt). This report breaks out the use of herbicides and insecticides on major field crops (corn, soybeans, winter wheat, cotton, and potatoes) in 1995 by the various tillage systems, crop rotations, plant densities, row sizes, and number of cultivations that were used in producing these crops.

"The Microeconomic Impact of IPM Adoption," *Agricultural and Resource Economics Review*, October 1996 (Jorge Fernandez-Cornejo). This report develops a methodology to calculate the impact of integrated pest management (IPM) on pesticide use, yields, and farm profits. While the methodology in this case study is applied to IPM adoption among fresh market tomato producers for insect and disease management, the method is of general applicability. It accounts for "self-selectivity" (IPM adopters may be better farm managers or differ systematically from nonadopters in some other way) and simultaneity—farmers' IPM adoption decisions and pesticide use may be simultaneous—and the pesticide demand and yield equations are theoretically consistent with a profit function. In this study, IPM was defined operationally as the use of scouting and thresholds for making insecticide and fungicide applications and the use of one or more additional IPM techniques for managing pests.

"The Diffusion of IPM Techniques by Vegetable Growers," *Journal of Sustainable Agriculture*, Vol. 7, No. 4 (Jorge Fernandez-Cornejo and Alan Kackmeister). This study examines the adoption/diffusion paths of various integrated pest management (IPM) techniques among vegetable growers in 15 states, as well as grower education, regional research levels, and other factors that influence adoption. The authors concluded that the IPM techniques examined would reach 75 percent adoption between 2008 and 2036, except for scouting, which attains the 75 percent level during the 1990's.

Organic Vegetable Growers Surveyed in 1994, AREI Updates, No. 4, May 1996 (Jorge Fernandez-Cornejo, Doris Newton, and Renata Penn). This statistical bulletin reports the first national level statistics on organic production practices in the U.S. vegetable industry. A sample of 303 organic vegetable growers, close to one-fifth of all certified organic vegetable growers, was obtained from the 1994 USDA Chemical Use Survey, and the report presents selected pest and nutrient management practices used by these growers, as well as socioeconomic statistics describing the growers.

"Factors Influencing Herbicide Use in Corn Production in the North Central Region," *Review of Agricultural Economics*, Vol. 17, No. 2, 1995, (Biing-Hwan Lin, Harold Taylor, Herman Delvo, and Leonard Bull). In this report, factors that influence herbicide use in corn production—including tillage practices, crop rotation, application method, and farm program participation—are analyzed using field-level data for 1990-1992 from the 10 major corn producing states. The authors found that herbicide use could be greatly reduced by switching from broadcast to band applications, and that switching from conventional to conservation tillage, without using the moldboard, plow sometimes increases herbicide use.

Adoption of Integrated Pest Management in U.S. Agriculture, AIB-707, September 1994 (Ann Vandeman, Jorge Fernandez-Cornejo, Sharon Jans, and Biing-Hwan Lin). This report summarized information on the extent of adoption of surveyed integrated pest management (IPM) techniques in the production of dozens of fruit and vegetable crops and several major field crops in the early 1990's. In this report, which was based on USDA survey data, farmers were considered to be using IPM if they scouted their crop acreage and based their decision to apply pesticides on whether pests had reached an economically damaging threshold. Using this definition, over half of the acreage of surveyed growers was being produced under IPM, with adoption rates and the additional pest management practices used, varying by crop and State.
(Contact to obtain reports: Catherine Greene, (202) 219-0466 [cgreene@econ.ag.gov])

4.5 Nutrient Management

Nutrients are essential for ensuring adequate crop yields and profitability but have long been associated with surface- and ground-water contamination. Many improved practices are available to reduce nutrient losses to the environment, with varying degrees of adoption by farmers. Improving nutrient management to reduce losses to the environment requires (1) a better understanding of the link between agricultural production and water quality; (2) agricultural R&D to develop scientifically and economically sound management practices; and (3) public policies and programs that specifically encourage the adoption of resource-conserving practices.

Contents

Profitable crop production requires significant amounts of nutrients in the form of commercial fertilizers and animal wastes (see chapter 3.1, *Nutrients*), portions of which can subsequently run off into surface waters or leach into groundwater. The two primary agricultural nutrients affecting water quality are nitrogen and phosphorus. Nitrogen, primarily found in the soil as nitrate, is soluble and easily transported by surface runoff, in tile drainage, or by leachate. Phosphorus, primarily in the form of phosphate, is not as soluble as nitrate and is primarily transported by sediment in runoff.

Why Manage Nutrients?

Excessive nitrogen or phosphorus in surface waters can cause algae to grow at an accelerated rate and cloud water, which prevents aquatic plants from receiving sunlight for photosynthesis. When the algae die and are decomposed by bacteria, they deplete the oxygen dissolved in the water and threaten aquatic animal life. This process, eutrophication, can result in clogged pipelines, fish kills, and reduced recreational opportunities or enjoyment. According to EPA, nutrient pollution is the leading cause of water quality impairment in lakes and estuaries and the third leading cause in rivers (1995). Above a certain concentration, nitrate is also a concern for drinking water. Based on the human health effects, EPA has established a maximum contaminant level of 10 mg/liter for nitrate in public drinking systems. Above this level, nitrates can cause methemoglobinemia, which prevents the transport of oxygen in the bloodstream of infants and may be a cancer risk to humans (EPA, 1992). (See chapter 2.2, *Water Quality*, for more information on agriculture's affect on water quality.)

Nutrient pollution of water resources can occur because of unusual wet weather that increases nutrient leaching and runoff. It can also occur when farmers are unaware of the offsite effects of their production decisions, or when they have no assigned cost or penalty for those effects and so choose production systems that may have greater profitability or less economic risk but higher nutrient losses.

Nutrient Balances—An Alternative Measure of Nutrient Use

Total or per-acre nutrient use is of limited value in determining whether nutrients pose an environmental threat. An alternative measure—nutrient mass or residual balance—calculates the residual nitrogen or phosphorus that may remain in the soil or be lost to the environment. Nutrient mass balances indicate how closely nutrient inputs (such as commercial fertilizer, animal manure, other wastes, and nutrients provided by previous legume crops) match nutrient outputs (the amount of nutrient taken up by the harvested crop). A positive net mass balance indicates the amount of residual nutrient that may remain in the soil or be lost to the air, carried by water runoff into surface-water systems, or carried by percolating water into ground water. However, residual nitrogen by itself does not necessarily result in water quality problems. For example, warm, moist soil conditions and dry air may volatilize residual nitrogen to the atmosphere, or vegetative buffers may capture residual nitrogen before it reaches water systems. Therefore, nitrate levels in surface and ground water in some areas of the Southeast tend to be low, even though residual nitrogen may be high.

A negative net balance indicates that the amount of nutrient removed from the field through the harvested crop exceeds the amount of nutrient applied, with the difference coming from nutrients stored in the soil or available through precipitation. Continued negative balances mine or deplete nutrients in soil, disrupt the soil ecosystem, and can damage soil productivity.

Residual balances can be computed on acres or fields to assist farmers in making nutrient management decisions. Calculating balances on a wider geographic area may portray the overall potential for nutrient losses and indicate where nutrient management could be improved. Using USDA's Cropping Practice Surveys, nutrient balances are calculated for major crops (see box, "Computing Nutrient Mass Balances"). Balance estimates are categorized as (1) *high* if the nutrient input exceeded the output in the harvested crop by more than 25 percent, (2) *moderate* if nutrient input exceeded output by less that 25 percent, and (3) *negative* if total nutrient input was less than the output. Declining percentages in the high and negative categories and an increasing percentage in the moderate category indicate improvements in nutrient management. No significant improvement is detected over the 1990-95 period (fig. 4.5.1, 4.5.2).

Computing Nutrient Mass (Residual) Balances

Per-acre, field-level data from the Cropping Practices Survey were used to estimate nutrient balances in pounds per acre for each nutrient on each sample field, using the following procedure:

NB = CF + L + NPK - H - (PR-CR), where

NB = **N**utrient **B**alance

CF = Nutrients from **C**ommerical **F**ertilizer in pounds applied per acre

L = Nitrogen from previous **L**egume crops. If the previous legume crop was soybeans, 1 pound of nitrogen credit was assumed for each bushel of soybeans harvested. If the crop in the previous year was first-year alfalfa, the nitrogen credit per acre was 50 percent of the nitrogen in harvested alfalfa. If the crop was second-year alfalfa, the nitrogen credit was 75 percent of the nitrogen in harvested alfalfa (Meisinger and Randall, 1991).

NPK = **N**itrogen, **P**hosphorus, and potassium (**K**) credits for applied manure for 1990-94 were estimated from two data sources: USDA's Area Study Survey (Alabama, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Maryland, Nebraska, and Minnesota) and the 1992 Agricultural Census (other States). The estimation procedures used were those developed by Van Dyne and Gilberson (1974) and by Gollehon and Letson (1996). The NPK credits for 1995 were estimated directly from survey data. The estimation procedures were from the *Agricultural Waste Management Field Handbook* (USDA, NRCS, 1992).

H = Nutrients assumed per unit of crop **H**arvested were 0.9 pound of nitrogen and 0.35 pound of phosphorus for each bushel of corn, 1.25 pounds of nitrogen and 0.625 pound of phosphorus for each bushel of wheat, and 0.05 pound of nitrogen and 0.013 pound of phosphorus for each pound of cotton lint and seed (Fertilizer Institute, 1982; Meisinger, 1984).

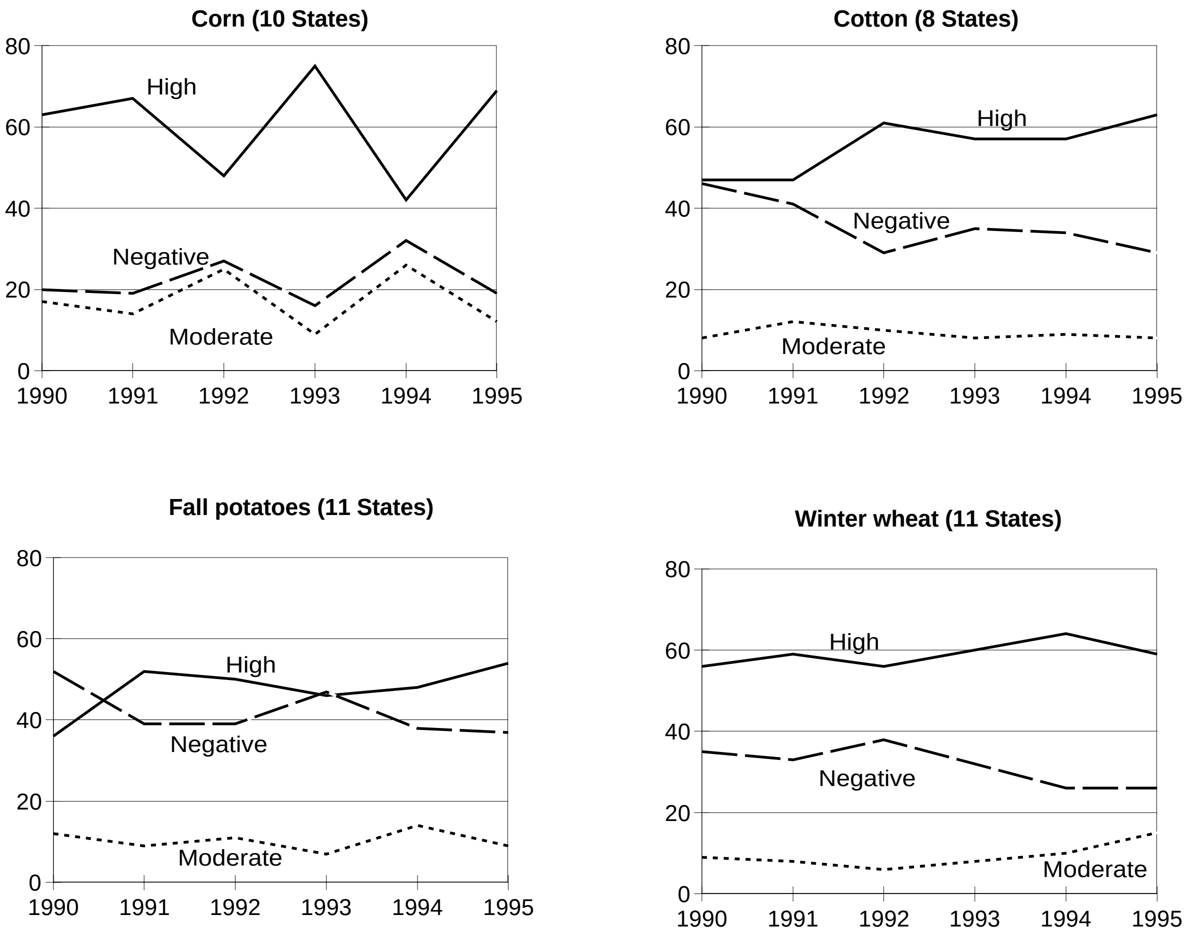
PR = Nutrients from **P**revious crop **R**esidue.

CR = Nutrients in **C**urrent crop **R**esidue remaining on the field.

Nutrients from plant residues are assumed to remain on the field and be equal in nutrient value at beginning and end of season.

State and crop-level estimates were developed by extrapolating and aggregating field-level data.

Figure 4.5.1--Nitrogen mass balances in major producing States, 1990-95: percentage of acres in high, moderate, and negative categories



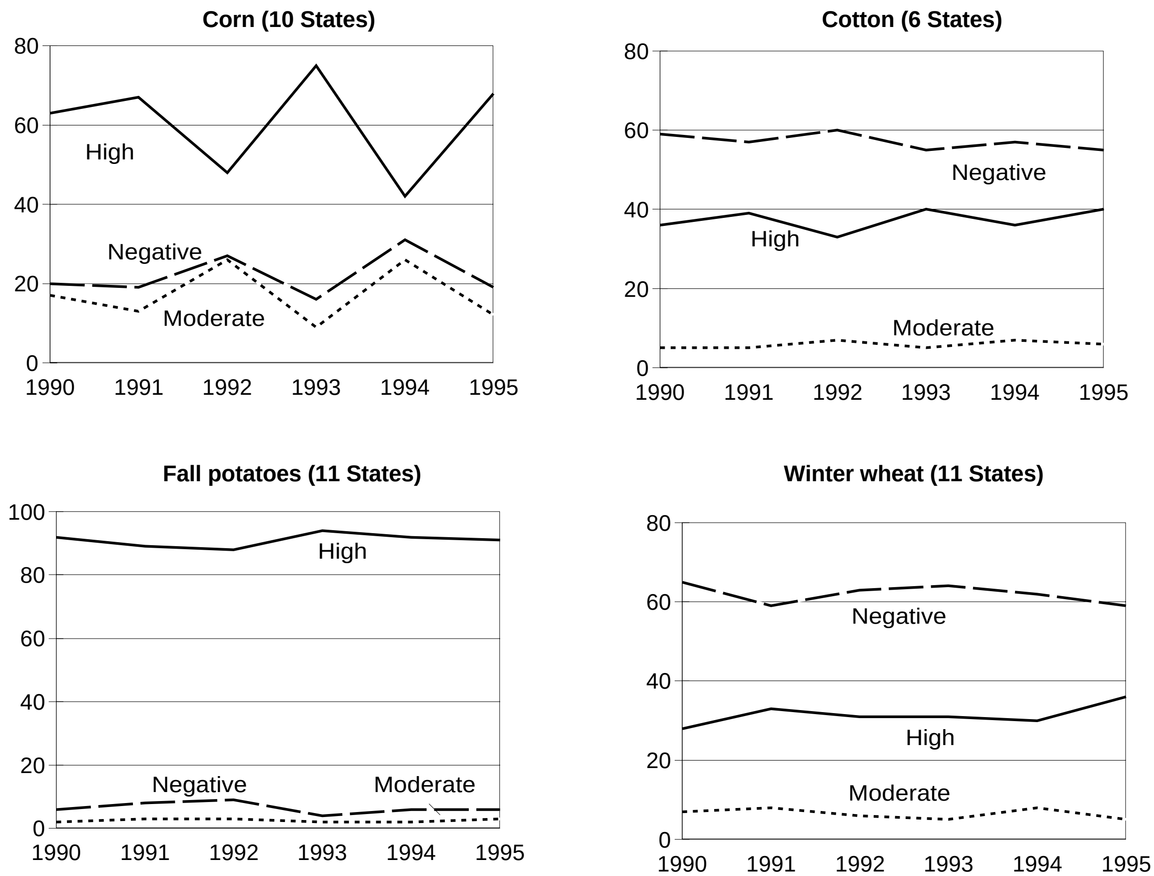
For States included, see "Cropping Practices Survey" in the appendix..

Source: USDA, ERS, estimates based on Cropping Practices Survey data.

Positive residual balances can occur if farmers underestimate available nutrients or overapply nitrogen—the most critical nutrient—in order to support high crop yields. Other factors are the relatively low marginal cost of applying extra nutrients at the time of initial application in the fall and spring before planting and the extra cost and uncertainty (due to weather delays) of making a timely, second application if needed after planting. High nutrient balances also occur when poor weather or excessive pest damage result in crop yields lower than farmers anticipate and less nutrients are taken up by the harvested crop. Consequently, balances may vary significantly from year to year. Persistent high balances on land vulnerable to leaching can be of particular concern for groundwater quality (see chapter 2.2, *Water Quality*, for areas vulnerable to groundwater contamination).

Nitrogen balances. Over half of the corn, cotton, potato, and wheat acres in major producing States had high nitrogen mass balances during 1990-95, suggesting potential nitrogen losses to the environment (fig. 4.5.1, table 4.5.1). Also, in most years, one-fifth or more of these acres had negative nitrogen balances, indicating the mining of nitrogen in the soil to supply crop needs. The percentage of corn acres with high nitrogen balance varies considerably from year to year mainly due to annual variation in yield and crop nutrient uptake. The percentages of cotton and wheat acres with a high nitrogen balance have been increasing, as farmers appear to be applying more nitrogen fertilizer in anticipation of higher crop prices in recent years (NASS, 1996).

Figure 4.5.2--Phosphate mass balances in major producing States, 1990-95: percentage of acres in high, moderate, and negative categories



For States included, see "Cropping Practices Survey" in the appendix.
Source: USDA, ERS, estimates based on Cropping Practices Survey data.

Phosphorus balances. High phosphate balances occurred on 36 percent (winter wheat) to 94 percent (potatoes) of major field crops during 1990-95 (fig. 4.5.2, table 4.5.2). In areas with high soil erosion and runoff, the high residual balance of phosphorus could contribute to water quality problems and require improved management. Phosphorus is more stable than nitrogen and more likely to remain in the soil with less loss to the environment unless the soil itself erodes away. Because of this greater stability, and to reduce costs, many farmers apply extra phosphorus one year then skip a year or more (USDA, NRCS 1995a). The large percentage of acres with negative mass balances is also evidence of this practice.

Nutrient Management Practices

Effective nutrient management, which includes assessing nutrient need, timing nutrient application, and placing nutrients close to crop roots, can help reduce nutrient losses to the environment while sustaining long-term productivity and profitability. The efficacy of each practice is strongly influenced by the conditions in each field, the farmer's management knowledge and skill, economic factors, and weather (table 4.5.3).

Assessing nutrient needs. Farmers following conventional practices may apply fertilizer at rates based on optimistic yields and may not account for all sources of nutrients. Improved management requires more information about the nutrients available for crop needs and the use of balances to better assess nutrient need. In addition to computing acre- or field-

Table 4.5.1—Nitrogen mass balances for selected crops in major producing states, 1990-95[1]

Crop and year	Acres	Nutrient inputs: Commer-cial fertilizer	Previous legumes	Manure	Total	Nutrient output in harvested cropland	Nutrient mass balance: Average	Above 25 percent	0-25 percent	Negative
	1,000	*Average pounds per acre*						*Percent of acres*		
Corn										
1990	58,700	130	21	6	157	113	44	63	17	20
1991	60,350	128	22	7	157	102	55	67	14	19
1992	62,700	128	22	6	156	128	28	48	25	27
1993	57,300	123	24	6	153	92	61	75	9	16
1994	62,500	127	21	6	154	131	23	42	26	32
1995	52,200	130	28	2	160	105	55	69	12	19
Cotton										
1990	8,444	68	3	3	74	54	20	47	8	46
1991	10,850	79	3	4	86	62	24	47	12	41
1992	10,115	86	1	4	91	60	31	61	10	29
1993	10,126	80	2	3	85	57	28	57	8	35
1994	10,023	95	2	4	101	61	40	57	9	34
1995	10,480	82	2	3	87	47	40	63	8	29
Potatoes										
1990	624	191	7	5	203	149	54	56	9	35
1991	655	176	4	1	181	141	40	59	8	33
1992	607	183	3	1	187	161	26	56	6	38
1993	647	177	3	1	181	139	42	60	8	32
1994	652	246	3	--	249	142	107	64	10	26
1995	669	206	1	1	208	138	70	59	15	26
Wheat, Winter										
1990	38,650	51	0	1	52	49	3	36	12	52
1991	30,980	53	5	1	59	41	18	52	9	39
1992	33,465	54	4	1	59	44	15	50	11	39
1993	35,210	53	4	1	58	48	10	46	7	47
1994	32,930	56	4	1	61	45	16	48	14	38
1995	32,670	57	6	1	64	43	21	54	9	1

-- = Less than 0.5
[1] See "Cropping Practices Survey" in the appendix for major producing States included.
Source: USDA, ERS, estimates based on Cropping Practices Survey data (see box, "Computing Nutrient Mass Balances").

level mass balances, analyzing plant tissue during the growing season can detect any emerging nitrogen deficiency. Soil nitrogen tests can be administered both when a majority of fertilizer is applied before planting and when a majority is applied as a side-dress application.

Soil tests for nitrogen, phosphorus, potassium, PH levels, and micronutrients, though essential for improving nutrient management, are an additional expense that many farmers forgo. Nevertheless, soil nitrogen tests and plant analysis can help farmers improve their net farm income (Babcock and Blackmer, 1994; Shortle et al., 1993; Bosch et al., 1994). In particular, soil tests help those farmers who underestimate the nutrient carryover from the previous season to avoid overapplying, thus reducing nitrogen loss and improving their net farm income (Huang et al., 1996). The economic benefit of soil nitrogen testing is greatest in fields where manure was applied and where the previous season was dry (Bosch et al., 1994; Bock et al., 1992; Fuglie and Bosch, 1995). The ideal time to conduct soil nitrogen testing and application is just before plants require nutrients, because nitrogen (as nitrate in the soil) quickly dissipates. However, benefits to the farmer from soil nitrogen tests may disappear if weather conditions prevent farmers from entering fields soon after testing. Because phosphorus is relatively stable in the soil, testing for this nutrient can be conducted any time before fertilization.

Table 4.5.2—Phosphate mass balances for selected crops in major producing States, 1990-95[1]

Crop and year	Acres	Nutrient inputs: Commercial fertilizer	Nutrient inputs: Previous legumes	Nutrient inputs: Manure	Nutrient inputs: Total	Nutrient output in harvested cropland	Nutrient mass balance: Average	Nutrient mass balance: Above 25 percent	Nutrient mass balance: 0-25 percent	Nutrient mass balance: Negative
	1,000	*Average pounds per acre*						*Percent of acres*		
Corn										
1990	58,700	52	0	6	58	44	14	50	12	38
1991	60,350	52	0	7	59	40	19	54	11	36
1992	62,700	47	0	5	52	50	2	36	14	50
1993	57,300	47	0	6	53	36	17	57	10	33
1994	62,500	48	0	6	54	51	3	37	13	50
1995	52,200	47	0	2	49	41	8	43	11	46
Cotton										
1990	8,444	23	0	2	25	26	-1	36	5	59
1991	10,850	26	0	3	29	30	-1	39	5	57
1992	10,115	27	0	4	31	29	2	33	7	60
1993	10,126	26	0	3	29	28	1	40	5	55
1994	10,023	24	0	4	28	30	-2	36	7	57
1995	10,480	23	0	2	25	23	2	40	6	55
Potatoes										
1990	624	159	0	6	165	28	137	92	2	6
1991	655	43	0	1	144	27	117	89	3	8
1992	607	146	0	1	147	30	117	88	3	9
1993	647	148	0	1	149	26	123	94	2	4
1994	652	171	0	--	171	27	144	92	2	6
1995	669	157	0	1	158	26	132	91	3	6
Soybeans										
1990	39,600	10	0	3	13	34	-21	13	4	83
1991	41,850	9	0	3	12	33	-21	13	3	84
1992	41,600	10	0	3	13	37	-24	11	7	82
1993	42,300	9	0	3	12	32	-20	13	5	82
1994	43,750	10	0	3	13	40	-27	9	5	86
1995	41,700	11	0	1	12	35	-22	13	3	84
Wheat, Winter										
1990	38,650	19	0	1	20	25	-5	28	7	65
1991	30,980	20	0	1	21	21	0	33	8	59
1992	33,465	18	0	1	19	22	-3	31	6	63
1993	35,210	19	0	1	20	24	-4	31	5	64
1994	32,930	19	0	1	20	23	-3	30	8	62
1995	32,670	20	0	1	21	22	-1	36	5	59

-- = Less than 0.5

[1] See "Cropping Practices Survey" in the appendix for major producing States included.

Source: USDA, ERS, estimates based on Cropping Practices Survey data (see box, "Computing Nutrient Mass Balances").

In 1995, soil testing ranged from 22 percent of winter wheat acres to 83 percent of potato acres (tables 4.5.4-4.5.9). The extent of soil testing varies from year to year, but during 1990-95, most soil testing included nitrogen testing, and soil testing for nitrogen increased on potatoes and soybeans.

Testing of plant tissues during the growing season indicates any emerging nutrient deficiency, which can then be corrected by an additional nutrient application. With tissue testing, farmers can apply fertilizers at lower rates based on realistic or average yield expectations, then detect and correct (if economical to do so and if conditions permit) any deficiency that might result from above-average growing conditions. In 1994, the only year data were collected, farmers used tissue testing (primarily for nitrogen) on 61 percent of potato acres (table 4.5.7)and 12 percent of cotton acres (table 4.5.6).

Table 4.5.3—Nutrient management operations and improved versus conventional practices

Nutrient management operation	Conventional practices	Improved practices
Assessing nutrient need	Limited testing for residual nutrient levels, or plant tissue tests to detect nutrient deficiency in plant before applying nutrients.	Annual or regular soil and plant tissue testing before applying nutrients.
	Limited use of the nutrient mass balance accounting method to determine appropriate application rate. Amount applied based on recommended rates for yield maximization, with no crediting for nutrients from other sources.	Nutrient mass balance accounting method used to determine appropriate application rate based on recommended rate for realistic yield goal, with crediting given for nutrients in previous legume, irrigation water, and manure. Manure analyzed for nutrients.
	Same application rate on all parts of field.	Nutrient application rates varied according to the yield potential of soil in various parts of the field.
	The importance of soil factors overlooked.	Optimal levels of soil factors—such as soil PH, organic matter, and micro-nutrients—maintained.
Timing nutrient application	Fall and early spring applications of nitrogen before planting.	Split application of nitrogen fertilizer at planting and after planting.
	Application sometimes made before expected heavy rain.	No application before expected heavy rain.
Nutrient placement	Ground and air broadcast, and application in furrow.	Banded and injected (knifed-in) applications, and chemigation.
Nutrient product selection	Nitrate-based fertilizer sometimes used on high leaching field, and ammonia-based fertilizer on high volatilization field.	Ammonia-based fertilizer used on high leaching field, and nitrate-based fertilizer for low leaching field. Nitrogen stabilizers used in ammonia-based nitrogen fertilizer.
	No application of manure to increase organic matter in soil.	Manure applied to increase organic matter in soil.
Crop selection and management	Continuous planting of same nitrogen-using crop. No planting of cover crops between crop seasons.	Nitrogen-using crops rotated with nitrogen fixing crops. Cover crops planted between crop seasons to tie up and preserve nutrients.
Irrigation management	Conventional gravity irrigation with an excessive application of water.	Improved gravity irrigation practices or sprinkler irrigation used to apply water more timely and uniformly according to crop needs.
Manure and organic waste management	Crop residues removed. No manure or organic waste applied. No manure testing. Inadequate manure storage for properly timing manure applications.	Manure and organic waste application based on manure and waste test results and nutrient management plan. Adequate manure storage for timing manure application, with manure injected or incorporated into soil.

Source: USDA, ERS.

Table 4.5.4—Nutrient management practices on corn, 10 major producing States, 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	97	97	97	97	98	98
Manure only	1	1	1	1	1	1
Commercial and manure	16	18	15	17	15	13
Previous soybeans	40	40	44	46	48	50
Previous legume hay and pasture	8	7	8	5	7	7
Assessing nutrient need:			*Percent of planted acres*[2]			
Soil tested	41	41	42	38	42	34
Tested for N	61	60	82	77	54	53
Applied recommended N	na	na	85	87	84	78
Applied > recommended	na	na	5	3	7	7
Applied < recommended	na	na	10	10	9	14
Manure analyzed for manure treated acres	na	na	na	na	6	8
N adjusted for manure-analyzed acres	na	na	na	na	70	na
N adjusted for previous legume	na	na	na	na	53	54
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	27	26	23	20	27	30
Spring before planting	57	50	53	51	54	52
At planting	44	48	47	48	43	42
After planting	26	31	31	35	27	29
Phosphate timing:						
Fall before planting	na	na	na	na	25	26
Spring before planting	na	na	na	na	34	31
At planting	na	na	na	na	48	48
After planting	na	na	na	na	2	2
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	71	72	69	71	72	73
Broadcast (air)	na	na	1	1	1	1
Chemigation	1	2	1	1	1	1
Banded	43	41	42	42	41	40
Foilar	1	0	0	-	-	0
Injected (knifed in)	55	53	54	47	53	51
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	26	30	29	29	23	26
Urea	3	2	2	3	2	2
Ammonium nitrate	-	-	-	-	-	-
Nitrogen solutions (urea, ammonia, ammonia nitrate)	44	44	47	45	51	49
Mixed NPK fertilizers	24	24	21	23	24	23
N fertilizers mixed with N inhibitors (percent of acres)	8	9	8	5	9	10
Crop selection and management:			*Percent of planted acres*			
Continuous same crop	24	25	23	25	22	21
Corn soybean rotations	40	40	44	46	48	47
Planted after other row crops or small grains	23	16	18	17	17	19
Planted with cover crops	0.5	0.8	0.5	0.5	0.5	0.7

na = no data collected. - means less than 0.5.
[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.
Source: USDA, ERS, Cropping Practices Survey data

Table 4.5.5—Nutrient management practices on soybeans, 8 major producing States, 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	27	26	27	27	28	28
Manure only	4	6	7	6	8	5
Commercial and manure	2	2	2	1	2	1
Soybeans	12	10	20	11	12	11
Legume, hay and pasture	3	2	3	1	3	2
Assessing nutrient need:			*Percent of planted acres*[2]			
Soil tested	26	28	28	28	30	25
Tested for N	15	16	29	29	43	41
Applied recommended N	na	na	85	87	76	74
Applied > recommended	na	na	5	3	5	7
Applied < recommended	na	na	10	10	18	19
Manure analyzed for manure treated acres	na	na	na	na	5	8
N adjusted for manure-analyzed acres	na	na	na	na	75	na
N adjusted for previous legume	na	na	na	na	16	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	25	26	33	27	31	35
Spring before planting	50	46	43	51	42	43
At planting	22	24	17	21	24	19
After planting	7	8	8	4	7	8
Phosphate timing:						
Fall before planting	na	na	na	na	42	41
Spring before planting	na	na	na	na	40	42
At planting	na	na	na	na	17	16
After planting	na	na	na	na	3	2
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	87	85	89	90	88	88
Broadcast (air)	na	na	na	1	1	2
Chemigation	1	2	1	1	-	-
Banded	14	14	9	9	11	11
Injected (knifed in)	2	4	1	1	2	3
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	7	18	6	5	7	6
Urea	4	7	13	2	6	1
Ammonium nitrate	1	0	0	0	0	-
Nitrogen solutions	15	19	10	25	13	25
Mixed NPK fertilizers	73	57	71	68	74	68
N fertilizer mixed with N inhibitors (percent of acres)	-	-	-	-	-	-
Crop selection and management:			*Percent of planted acres*			
Continuous same crop	6	7	13	6	7	6
Corn/soybean rotation	56	55	36	58	57	63
Planted after other row crops or small grains	31	28	27	28	26	16
Planted with cover crops	3	3	4	3	3	4

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Table 4.5.6—Nutrient management practices on cotton, 6 major producing States, 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	80	82	80	85	87	87
Manure only	0.6	0.9	-	0.6	0.5	-
Commercial and manure	3.3	2.1	3.2	3.0	2.9	2.5
Previous legume hay or pasture	4	4	2	3	2	3
Assessing nutrient need:			*Percent of planted acres*[2]			
Soil tested	28	32	27	28	33	27
Tested for N	95	88	98	94	88	95
Applied recommended N	na	na	76	79	81	73
Applied > recommended	na	na	13	19	9	14
Applied < recommended	na	na	11	8	10	13
Tissue tested	na	na	na	na	12	na
Tested for N	na	na	na	na	96	na
Applied recommended N	na	na	na	na	97	na
Applied > recommended	na	na	na	na	0	na
Applied < recommended	na	na	na	na	3	na
Manure analyzed for manure treated acres	na	na	na	na	23	31
N adjusted for manure-analyzed acres	na	na	na	na	100	na
N adjusted for previous legume	na	na	na	36	na	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	30	32	30	30	31	32
Spring before planting	42	46	36	43	45	43
At planting	8	11	10	8	7	7
After planting	56	57	59	58	53	52
Phosphate timing:						
Fall before planting	na	na	na	na	40	37
Spring before planting	na	na	na	na	49	47
At planting	na	na	na	na	4	4
After planting	na	na	na	na	11	17
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	56	58	55	55	60	55
Broadcast (air)	na	na	5	6	6	3
Chemigation	7	8	6	6	8	6
Banded	24	27	25	24	20	29
Foliar	0	4	3	2	-	-
Injected (knifed in)	45	45	42	45	46	40
Type of nitrogen fertilizer:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	26	30	28	22	25	27
Urea	5	6	3	5	3	2
Ammonium nitrate	2	1	-	-	-	1
Nitrogen solutions	44	36	41	47	52	45
Mixed NPK fertilizers	24	26	27	26	21	26
N fertilizer mixed with N inhibitors (percent of acres)	4	6	3	3	4	na
Crop selection and management:			*Percent of planted acres*			
Continuous crop without cover crop	61	61	66	69	69	68
Continuous crop with cover crop	2	3	2	2	1	1
Cotton-sorghum rotation	8	6	7	12	6	5
Planted after other row crops or small grains	19	17	19	18	18	17

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Table 4.5.7—Nutrient management practices on fall potatoes, 11 major producing states 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	99	99	100	100	100	100
Manure only	-	-	-	-	-	-
Commercial and manure	5.2	4.0	3.5	3.3	2.3	2.3
Previous legume hay or pasture	21	8	5	7	12	10
Assessing nutrient need:			*Percent of planted acres*[2]			
Soil tested	83	84	82	84	85	83
Tested for N	77	77	82	84	92	94
Applied recommended N	na	na	79	77	76	73
Applied > recommended	na	na	9	11	10	10
Applied < recommended	na	na	12	12	14	17
Tissue tested	na	na	na	na	61	na
Tested for N	na	na	na	na	60	na
Applied recommended N	na	na	na	na	83	na
Applied > recommended	na	na	na	na	3	na
Applied < recommended	na	na	na	na	14	na
Manure analyzed for manure treated acres	na	na	na	na	13	43
N adjusted for manure-analyzed acres	na	na	na	na	13	na
N adjusted for previous legume	na	na	na	na	54	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	16	22	19	20	30	28
Spring before planting	37	41	36	35	43	40
At planting	59	56	53	54	41	46
After planting	52	60	57	57	63	73
Phosphate timing:						
Fall before planting	na	na	na	na	28	27
Spring before planting	na	na	na	na	39	37
At planting	na	na	na	na	41	46
After planting	na	na	na	na	28	30
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	na	na	na	na	76	79
Broadcast (air)	na	na	na	na	9	7
Chemigation	na	na	na	na	45	48
Banded	na	na	na	na	51	47
Foilar	na	na	na	na	2	-
Injected (knifed in)	na	na	na	na	6	14
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	5	7	6	8	5	5
Urea	3	3	3	3	2	10
Ammonium nitrate	2	1	-	-	-	1
Nitrogen solutions (urea, ammonium nitrate, ammonia)	44	36	41	47	52	45
Mixed NPK fertilizers	24	26	27	26	22	26
Mixed with N inhibitors (percent of acres)	4	4	2	6	5	na
Crop selection and management:			*Percent of planted acres*			
Continuous same crop without cover crop	1	3	2	3	2	4
Continuous same crop with cover crop	2	2	1	2	1	2
Continuous row crops	14	17	16	16	16	19
Planted after other row crops or small grains	50	44	50	47	51	45

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Table 4.5.8—Nutrient management practices on winter wheat, 11 major producing States 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	83	83	84	86	86	86
Manure only	-	-	-	-	0.6	1.3
Commercial and manure	1.8	2.7	2.1	2.6	1.8	1.2
Previous legume hay and pasture	4	1	1	-	1	1
Assessing nutrient need:			*Percent of planted acres*[2]			
Soil tested	17	19	23	22	20	22
Tested for N	92	92	95	93	91	91
Applied recommended N	na	na	77	77	78	63
Applied > recommended	na	na	7	9	7	15
Applied < recommended	na	na	16	15	15	21
Manure analyzed for manure treated acres	na	na	na	na	na	12
N adjusted for manure-analyzed acres	na	na	na	na	13	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing						
Fall before planting	68	73	73	72	76	77
At planting	22	22	21	22	23	23
After planting	44	45	47	44	42	47
Phosphate timing:						
Fall before planting	na	na	na	na	57	57
At planting	na	na	na	na	38	38
After planting	na	na	na	na	7	7
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	na	na	na	na	58	62
Broadcast (air)	na	na	na	na	3	3
Chemigation	na	na	na	na	1	1
Banded	na	na	na	na	19	21
Injected (knifed in)	na	na	na	na	46	46
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	43	43	46	45	47	46
Urea	12	10	9	6	5	5
Ammonium nitrate	1	2	2	2	1	3
Nitrogen solutions (ammonia, urea, ammonium nitrate)	21	24	22	24	24	24
Mixed NPK fertilizers	23	21	22	24	24	24
N fertilizer mixed with N inhibitors (percent of acres)	2.6	2.3	1.9	1.3	2.0	na
Crop selection and management:			*Percent of planted acres*			
Continuous same crop	51	40	40	39	43	45
Wheat/fallow/wheat	na	21	20	23	23	19
Idle or fallow	27	34	23	23	21	18
Double-cropped soybeans	2	2	2	1	1	1

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Of the acres soil-tested for nitrogen, farmers typically reported applying the recommended amount for the soil and crop. Whether nitrogen tests help reduce nitrogen fertilizer use depends in part on the nitrogen recommendations provided to farmers by the State Extension Service or fertilizer dealers. However, Schlegel and Havlin (1995) found that the nitrogen rates recommended by typical models were sometimes 30 to 60 percent higher than the profit maximizing rate.

The nutrient content of any manure applied, if known, allows farmers to better determine nutrients needed from other sources. However, manure analysis occurred on only 8 percent of corn and soybean acres receiving manure in 1995, and on only 12 percent of wheat acres (tables 4.5.4-4.5.8). Previous legumes, an additional source, were credited by farmers in determining commercial nutrient needs on only about half of crop acres with previous legumes.

Timing nutrient application. Timing nitrogen applications to the biological needs of a crop leaves less nitrogen available for loss and can reduce total amount applied. Optimum times for fertilizer application vary by crop, texture of soil, climate, and stability of fertilizer (Aldrich, 1984). For example, corn requires most of its nitrogen supply in midsummer. Nitrogen applied either in the fall or early spring is more readily lost to the environment than when applied at or after planting, and farmers often apply a larger amount to make up for the anticipated loss. Splitting nitrogen fertilizer into various applications at and after planting can reduce nitrogen loss by as much as 40 percent without reducing crop yields (Meisinger and Randall, 1991). However, fall and early spring applications are still prevalent, and may be increasing for some crops. Over two-thirds of winter wheat acres and 20-35 percent of corn, soybean, cotton, and potato acres were fertilized in the fall before planting during 1990-95. The trend appears to be increasing for potatoes and winter wheat. Another 35-57 percent of soybean, cotton, potato, and corn acres received fertilizer in the spring before planting. The only major field crop with increases in after-planting applications was fall potatoes, and this at the expense of at-planting application.

Economic considerations lead many farmers to apply nitrogen before planting during the fall and spring rather than during the growing season (Feinerman et al., 1990; Huang et al., 1994). For example, uncertain weather conditions may shorten the window (time) in which fertilizer can be applied during the growing season, increasing the risk of yield loss from inadequate nitrogen availability. Such risk is magnified for farmers with shorter growing seasons. The opportunity cost of labor and application arrangements may be significantly higher during the late spring and growing season than during the fall. Also, fertilizer pricing patterns (lower in the fall than spring) tend to encourage fall application rather than spring or growing-season application.

Nutrient placement. For crops surveyed in the Cropping Practices Survey, broadcasting was the most common method of applying fertilizers. Broadcasting keeps down the cost of field operations but broadcast nitrogen is more susceptible to loss to the environment. In contrast, banded applications—including the use of injection, knifed-in, or side dressing (see glossary)—place nitrogen fertilizer closer to the seed or plant for increased crop uptake (Achorn and Broder, 1991). Banded practices can increase the efficiency of nitrogen fertilizer use. Injection of an ammonia type of nitrogen (such as anhydrous ammonia) into the soil can reduce leaching and volatilization by as much as 35 percent compared with broadcast application (Achorn and Broder, 1991) and can result in a yield increase of as much as 15 percent (Mengel, 1986). The operation cost (variable and fixed) of injection applications is higher than for broadcast applications, but the overall cost (operation and nitrogen fertilizer) is lower.

Precision farming, also referred to as site-specific farming, is a promising new technology for improving nutrient application timing, rate, and placement. This technology divides whole fields into small areas and uses a variable-rate fertilizer spreader and a global positioning system to apply the exact amount of nutrient needed at each specific location. Precision farming requires equipment for testing soils, locating position, and monitoring yields; a computer to store data; and a variable-rate applicator (see the chapter on Farm Machinery for more detail). A preliminary estimate of additional field operation costs of precision farming for corn is about $7-$8 per acre (Lowenberg-DeBoer and Swinton, 1995).

Precision farming has the potential to improve net farm income by: (1) identifying places in a field where additional nutrient use will increase yield, and thus farm income, by more than the added cost; and (2) identifying places where reduced input use will reduce costs while maintaining yield. Precision farming has the potential to reduce off-site transport of agricultural chemicals with surface runoff, subsurface drainage, and leaching (Baker and others, 1997). Two years of Kansas field data indicate less total nitrogen fertilizer use with precision farming than with conventional nitrogen management (Snyder and others, 1997). However, precision farming is too new an information technology to assess how it affects long-term yield, fertilizer use, farm-level productivity, and the enironment.

Nutrient product selection. Nitrogen fertilizers can be ranked according to their chemical stability in the soil—an important factor in determining potential for environmental harm. Ammonium nitrate is the least stable in soil, followed by nitrogen solutions, anhydrous ammonia, urea, and ammonia-based fertilizer with an added nitrification inhibitor (Fertilizer Institute, 1982; Aldrich, 1984). For areas where cropland is vulnerable to leaching (sandy soils), ammonia-based fertilizer can minimize nitrogen loss. For areas where ammonia volatilization is a problem (areas with hot, dry air and moist soils), a nitrate-based fertilizer is preferable.

Nitrogen stabilizers or inhibitors (urease inhibitors and nitrification inhibitors) delay the transformation of nitrogen fertilizer from ammonia to nitrate and help match the timing of nitrate supply with peak plant demand (Hoeft, 1984). The potential benefit from nitrification inhibitors is greatest where soils are either poorly or excessively drained, no-till cultivation is used, nitrogen is applied in the fall, crops require a large amount of nitrogen fertilizer, and excessively wet soil conditions prevent the application of nitrogen in the growing season (Hoeft 1984; Nelson and Huber, 1987; Scharf and Alley, 1988). The greatest potential benefit occurs only when nitrification inhibitors are used at or below the optimal nitrogen application rate. A nitrification inhibitor added to anhydrous ammonia is most widely used in corn production. However, recent surveys reveal that corn growers in the Corn Belt are likely to apply more nitrogen fertilizer when a nitrification inhibitor is used. Such a practice not only diminishes the economic benefit associated with the use of a nitrification inhibitor, but also increases the amount of residual nitrogen left on the field for leaching (Huang and Taylor, 1996). During 1990-95, farmers used nitrification inhibitors on acreage ranging from 2 percent of winter wheat to 10 percent of corn (tables 4.5.4-4.5.8). No trends are evident.

Crop selection and management. Crops in rotation with a nitrogen-fixing legume crop can reduce nitrogen fertilizer needs and use. In addition, crops in rotation reduce soil insect species, improve plant health, and increase nitrogen uptake efficiency. Legume crops at the early stage of growth absorb residual nitrogen in the soil and therefore minimize nitrate leaching. Even with these benefits, however, crop rotations are often less profitable than monoculture particularly when crop production is subsidized by farm programs. For example, a corn-soybean rotation was shown to be less profitable than continuous corn production under farm programs that included loan rates and deficiency payments (Huang and Lantin, 1993; Huang and Daberkow, 1996). Nevertheless, more than 40 percent of corn on nonirrigated land is in rotation with soybeans or other crops to buffer uncertain markets and to aid in pest control (see chapter 4.3, *Cropping Management*, for more detail on rotations and the economic factors that influence crop choice).

Planting cover crops between crop seasons can prevent the buildup of residual nitrogen. Planting cover crops also can reduce nutrient loss by minimizing soil erosion. Small grain crops and hairy vetch are both nitrogen-scavenging cover crops. Because the economic benefit of planting cover crops is limited for field crops, the practice has not been widely adapted by U.S. farmers. During 1990-95, only 1-4 percent of major field crop acres had previous cover crops (tables 4.5.4-4.5.8).

Irrigation management. Improved irrigation practices can help farmers irrigate crops more uniformly and control the quantity of irrigation water in the soil (see chapter 4.6, *Irrigation Water Management*, for more details). The quantity of water in the soil affects the nutrient concentration in the soil and the rate of nutrient movement to the root zone (Rhoads, 1991). Too much irrigation water can promote nitrogen leaching, reduce nutrient concentration in the soil, and lower plant uptake. Too little irrigation water can stunt plant growth and reduce crop yield. Irrigation efficiency can be improved, for example, by switching from gravity irrigation to sprinkler irrigation, by scheduling irrigation according to plant need, and by using improved gravity irrigation practices such as a surge system or shorter irrigation runs. The cost of irrigation improvements can be substantial, but the economic benefit from saved irrigation water and increased yield in some areas may offset the cost.

Manure and organic waste management. Manure is a good source of organic matter for the soil. In some cases, it can also be an economical, though limited, source of plant nutrients. The organic matter in soil provides a steady supply of nutrients to the plant, and conditions the soil for the plant to achieve higher yields. However, the nutrients contained in the organic matter can also be lost to the environment through soil ersion. Because of its bulk, the economic benefit of manure is limited by available storage and reasonable transport distance (Bouldin et al., 1984). The benefit of manure varies by region; application of manure in corn production is profitable for farmers in Iowa (Chase et al., 1991). Transfer of poultry litter from the litter-surplus areas to litter-deficiency areas in Virginia is economically viable (Bosch and Napit, 1992). Most feedgrain and confined-livestock farms can benefit from manure use for crop production (Gollehon and Letson, 1996). Managing nutrients in manure for crop use requires testing manure for its nutrient content, planning its efficient use in crop production, and storing it to minimize nutrient loss until the time of the crops' greatest need. (USDA, NRCS 1992). During 1990-95, manure application to major field crops ranged from 2-3 percent of winter wheat to 13-18 percent of corn acres (tables 4.5.4-4.5.8).

Improving Nutrient Management

Federal and State governments play an important role in helping reduce agricultural nonpoint pollution of water resources (EPA, 1991). EPA establishes minimum water quality standards and regulates animal waste discharges from large confined livestock operations under the Clean Water Act. States regulate input use and use zoning, land acquisition, and easements to preserve areas deemed important for protecting water resources.

Society, acting through government, can (1) adjust the anticipated costs or benefits of certain production practices through education, technical assistance, and by taxing inputs or by offering subsidies for practice adoption; (2) restrict or regulate certain production practices, such as the use of highly leachable fertilizers in vulnerable areas; (3) help create markets for pollutants; and (4) invest in research and development to find production practices that are less environmentally damaging. Approaches 1 and 3 are economic or incentive-based approaches and are often preferred because they allow maximum flexibility in meeting environmental goals at minimum cost.

USDA prefers voluntary, incentive approaches to deal with agricultural water pollution. This preference is based on the inherent difficulty in regulating nonpoint sources of pollution, and on the belief that when educated about the problems and provided technical and financial assistance, farmers will make improvements in production practices to achieve conservation and environmental goals. In passing the Federal Agriculture Improvement and Reform Act of 1996, Congress reaffirmed its preference for dealing with agricultural resource problems using voluntary approaches.

Efficiency of Financial Incentive Programs

A recent study of USDA's Water Quality Incentives Projects (WQIP)—which provided producers with financial assistance to make changes in nutrient and other management systems to restore or enhance water resources impaired by agricultural source of pollution— found that practices requiring minor, inexpensive changes in existing farm operations tended to be adopted more frequently than those involving more expensive changes (Feather and Cooper, 1995). Belief that adoption will increase profits was found to be the most common reason for adoption: familiarity with the improved management practice was found to be the second most important reason for adoption followed by beliefs that the practice improves on-farm water quality.

To determine the sensitivity of adoption to WQIP incentive payment levels, non-adopting producers were asked if they would adopt improved management practices given various hypothetical incentive payments. In many cases, the incentive payments required to achieve a 50-percent adoption rate were much greater than the actual payments for these practices. Practices requiring larger incentive payments were typically those which involved expensive changes in the farm operation.

The results of this study have several policy implications. First, the efficiency of financial incentive programs may be increased by targeting practices providing the largest reduction in pollution per dollar of incentive payment. Second, educational programs seem to be most successful with practices that involve small, inexpensive changes in the operation and are profitable to the producer. Water-quality benefits influence adoption decisions, but profitability is the most important factor. Thus, educational programs without substantial incentive payments may have limited success encouraging practices involving large expenditures. Third, both educational and financial incentive programs should recognize that large regional differences in adoption exist over geographical areas. Instead of implementing a uniform program across the nation, region specific programs may be more effective. Lastly, using both educational and financial incentives requires fewer resources and may be more successful than implementing each program separately. A financial incentive program, for example, could be combined with an educational program targeting different practices. These two programs could be combined by requiring producers to enroll in the educational program in order to receive incentive or cost-sharing payments.

Adjusting the anticipated costs or benefits of production practices. USDA provides educational, technical, and financial assistance to encourage adoption of nutrient management and other less polluting practices (see chapter 6.2, *Water Quality Programs*). Education helps farmers understand the need for improved practices and demonstrates the practices in operation while technical assistance helps install and implement the practices. Financial assistance can help offset the added cost or risk associated with practice adoption (see box, "Efficiency of Financial Incentive Programs").

The Federal Agriculture Improvement and Reform Act of 1996 established the Environmental Quality Incentives Program (EQIP) in USDA to replace most previous financial assistance programs and to better target assistance to areas most needing actions to improve or preserve environmental quality. One half of EQIP funding is to be directed to conservation practices relating to livestock production including waste and nutrient management improvement. The program may emphasize extensive or management type practices that are more cost effective than intensive structural type measures. Such direction would favor improved nutrient management. (See chapter 6.1, *Conservation and Environmental Programs Overview* for more information on EQIP).

The relative costs of nutrient management practices can be adjusted through input or discharge taxes, such as a tax on nitrogen applied in excess of nitrogen removed (Huang and LeBlanc, 1994). In effect, the residual nitrogen tax is an effluent tax, which induces farmers to adopt improved practices to reduce the residual. Also, it can generate revenue to support development and promotion of improved practices. A nitrogen fertilizer tax in Iowa generates revenue for research and extension activities in water quality improvement. More than $15 million of tax revenue is generated annually and used to develop and promote alternative farming practices to reduce nitrate leaching.

Regulatory approaches. Regulatory approaches can impose a lower cost on farmers than do fertilizer or discharge taxes (Huang and Lantin, 1992) and can be a least-cost approach for society when unseasonal weather occurs (Baumol and Oates, 1988). Laws and programs that limit farm nutrient use in the interests of the environment— including the Clean Water Act—are described in detail in chapter 6.2, *Water Quality Programs*. Imposing restrictions on nitrogen fertilizer use can affect farmers differently, depending on current production practices (Huang, Shank, and Hewitt, 1996).

Several States have established a regulatory agency to control nitrate leaching. Currently, 13 States require that livestock farms have comprehensive nutrient management plans that account for all sources of nutrients and that match nutrient application and availability to crop need (USDA, NRCS 1995b). In 1969, Nebraska created 24 multipurpose Natural Resources Districts (NRD's) and gave them authority to levy a local property tax to fund a wide variety of services to protect Nebraska's natural resources (Nebraska Association of Resources Districts, 1990). One district, the Central Platte NRD, suffers a high level of nitrate-nitrogen in the ground water (CPNRD, 1993, 1995). Three phases of regulation were established, depending on the groundwater nitrogen level, potential impact on municipal water supply, and nitrogen levels in the zone between crop roots and ground water. Restrictions on fertilizer use increase with each phase. Nearly all farm operators have complied, completing reports on nitrogen use, taking necessary soil and water tests, and cutting back their use of commercial nitrogen fertilizer. Since the regulatory program was established in 1987, nitrate concentrations in the ground water in some areas in the Central Platte Basin have been stabilized (CPNRD, 1995).

As animal operations become larger, more States are looking at ways of protecting the environment from animal waste. Large confined animal operations can present major water quality problems, and operations greater than 1,000 animal units are subject to point-source permits under the Clean Water Act. However, these permits address only storage of manure on the site, and not disposal. In 1993, Pennsylvania became the first State to pass a comprehensive nutrient management law aimed at concentrated animal operations. Animal operations with over two animal units per acre of land available for spreading must have a farmlevel nutrient management plan that demonstrates that waste is being safely collected and disposed of (Beagle and Lanyon, 1994). Land-use laws that affect agriculture are being used by municipalities, counties, and other local governments. Zoning ordinances are used in many areas, especially around the rural-urban fringe, to ban confined animal operations.

Establishing markets for pollutants. Another way to improve nutrient management is to facilitate the transfer of manure from those farms that have excess to those that need additional nutrients. This can be done by establishing a market for trading manure products and for gathering and exchanging technical information. A successful market for the poultry litter has been established in Arkansas, the largest broiler-

Glossary

Plant tissue analysis—A test that uses chlorophyll (or greenness) sensing to detect nitrogen deficiency during the plant glowing period. Correction of any nitrogen deficiency is then made through chemigation or other foliar application (Sander et al., 1994).

Nutrient recommendations—The rate of the plant nutrient to be applied is the difference between the amount of nutrients required by the crop based on a realistic yield goal and the amount of the nutrients already available for plant uptake, as determined by soil nutrient tests and nutrient credits for other sources. Many land grant universities provide nutrient recommendations based on information obtained from long-term field trials.

Credits for other nutrient sources—Other sources of nutrients include nitrogen from legumes planted in the previous crop, nitrate in irrigation water and precipitation, and nitrogen, phosphorus, and potassium in animal manure and other (such as municipal) wastes.

Split applications—Total fertilizer for crop need is split into several applications during the growth of the crop.

Chemigation—Nitrogen solutions applied through irrigation water.

Broadcast applications—Fertilizer broadcast in either granule or liquid form on all field surfaces. Most ground broadcast equipment for granular fertilizer uses one or two disks to broadcast fertilizer in 12- to 15-meter swaths. Nitrogen solutions are broadcast using various types of spray nozzles. Aircraft is used for aerial application.

Injection, knifed-in, or incorporation—Nitrogen fertilizer is injected or knifed-in usually 12-24 cm below the soil surface. It can also be incorporated into the soil by tillage. High-pressure liquid nitrogen such as anhydrous ammonia is the most common form of nitrogen injected into the soil. Nitrogen solutions in low-pressure liquid form are also injected into the soil.

Side-dressing or banded application—Granule or liquid nitrogen fertilizer is placed to one side of the plant or placed every other row at planting or during the growing season.

Precision (prescription or site-specific) farming—A large field is divided into small grids according to soil and nutrient conditions. Various rates of nutrients are applied to those grids according to their nutrient status by using locator equipment.

Nitrification inhibitors—Chemical compounds that can be added to the ammonia fertilizers to slow the conversion of ammonium nitrogen to nitrate nitrogen which is susceptible to leaching. N-inhibitors can be used with manure and other forms of organic nitrogen fertilizer.

Urease inhibitors—Chemical compounds that can be added to urea to slow the conversion of urea to ammonium and therefore to slow nitrate leaching.

Slow-release nitrogen fertilizer—Fertilizer coated with chemicals that can retard release of nitrogen from applied fertilizer and prolong the supply of nitrogen for plant uptake.

Rotating crops: A multi-year crop sequence, for example, nonlegume crops then legume crops.

Improved irrigation practices—Use of improved gravity irrigation, a sprinkler irrigation system, soil moisture testing, and an irrigation schedule to tailor irrigation to crop needs and to apply irrigation water uniformly.

Factors influencing vigorous crop growth—Selecting disease- and insect-resistant plant, planting a crop at optimal time, and using integrated pest management can improve plant health and increase nitrogen uptake and thus reduce nitrogen available for leaching.

Cover crops—Planting a cover crop after harvest to take up residual nitrogen and therefore minimize leaching.

Crop residues—Incorporation of crop residual into the soil helps immobilize residual nitrogen.

producing State. In 1991, Winrock International began a project aimed at transferring excess litter in the western part of the State to rice farmers in eastern Arkansas as a natural soil amendment to improve the fertility of zero-grade rice fields where topsoil has been scraped off (Winrock International, 1995). Rice straw, in turn, is an important bedding material for poultry houses in western Arkansas. A poultry litter hotline was launched in 1993 to link prospective buyers and sellers. Also, Tyson Foods, the largest poultry processor, approved the same trucks delivering clean bedding from the Delta area to its contracted poultry farms to back-haul litter from the poultry farms to the Delta rice farms, reducing the cost of transporting litter. An average of 30 litter buyers and sellers are listed on the hotline through the year, with double that number in December and January. The litter market has increased incomes of both poultry farmers and rice farmers, while mitigating water quality problems in western Arkansas.

Research, development, and demonstration. The Federal Government also plays a major role in research, development, and demonstration of improved nutrient management. During 1991-94, USDA funded various Hydrologic Unit Area (HUA) and Demonstration Projects (DP), which helped farmers to implement improved nutrient management over a wide range of geographic settings, agricultural types, and water quality problems across the Nation (USDA, NRCS, 1995a). Case studies of eight DP's and eight HUA's found reductions in annual nitrogen application because of the improved nutrient management practices. Also, USDA, in cooperation with the U.S. Geological Survey, U.S. Environmental Protection Agency, and State experiment stations, established various Management Systems Evaluation Areas (MESA's) to better understand the linkages between farming practices and water quality in the Midwest (ARS, 1995). Nutrient management is the major focus of these projects, which include monitoring activities, modification of farming systems, alternative and new farming practices, site-specific management, nitrogen testing, and socioeconomic studies of farming systems.

Author: Wen-yuan Huang, (202) 501-8289 [whuang@econ.ag.gov]. Contributors: Harold Taylor, Peter Feather, Lee Christensen, C.S. Kim, and Richard Magleby.

References

Achorn, F. P., and M. F. Broder (1991). "Mechanics of Applying Nitrogen Fertilizer," *Managing Nitrogen for Groundwater Quality and Farm Profitability*. Soil Science Society of America, Madison, WI.

Aldrich, S.R. (1984). "Nitrogen Management to Minimize Adverse Effects on the Environment," *Nitrogen in Crop Production*. Soil Science Society of America, Madison, WI.

Babcock, B.A., and A. M. Blackmer (1994). "The Ex Post Relationship Between Growing Conditions and Optimal Fertilizer Levels," Review of Agricultural Economics , Vol. 16, No. 3. Sept.

Baker, J.L., T.S. Colvin, and D.B. Jaynes (1997). "Potential Environmental Benefits of Adopting Precision Agriculture," in *Proceedings of the 3rd International Conference on Precision Agriculture*. June 23-26, 1996, Minneapolis, MN. Published by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Baumol, W.I., and W.E. Oates (1988). *The Theory of Environmental Policy*, 2nd edition, Cambridge Univ. Press.

Beagle, D.B., and L.E. Lanyon (1994). "Nutrient Management Legislation in Pennsylvania," *Journal of Soil and Water Conservation*, Vol. 49, No. 2, March/April.

Bock, B.R., K.R. Kelley, and J.J. Meisinger (1992). "Predicting N Fertilizer Needs In Humid Regions: Summary and Future Directions," *Predicting N Fertilizer Needs for Corn in Humid Regions*. Bulletin Y-226, National Fertilizer and Environmental Research Center. Tennessee Valley Authority, Muscle Shoals, AL.

Bosch, Darrell J., Keith O. Fuglie, and Russ W. Keim (1994). "Economic and Environmental Effects of Nitrogen Testing for Fertilizer Management." Staff Report AGES9413. U.S. Dept. Agr., Econ. Res. Serv. April.

Bosch D. J., and K. B. Napit (1992). " Economics of Transferring Poultry Litter to Achieve More Effective Use as Fertilizer," *Journal of Soil and Water Conservation*, Vol 47, No. 4, July-Aug.

Bouldin, D. R., S. D. Klausner, and W. S. Reid (1984). "Use of Nitrogen from Manure," *Nitrogen in Crop Production*. Soil Science Society of America, Madison, WI.

Central Platte Natural Resource District (1993, 1995). Central Platte NRD's Groundwater Management Programs, Nebraska.

Chase, C., M. Duffy, and William Lotz (1991). "Economic Impact of Varying Swine Manure Application Rates on Continuous Corn," J*ournal of Soil and Water Conservation*, Vol. 46, No. 6, Nov.-Dec.

Feather, M.P., and J. Cooper (1995). *Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution*. AIB-716, U.S. Dept. Agr., Econ. Res. Serv., May.

Feinerman, E., E.K. Choi, and S. R. Johnson (1990). "Uncertainty and Split Nitrogen Applications in Corn Production," *American Journal of Agricultural Economics*. 72: 975-984.

Fertilizer Institute (1982). *The Fertilizer Handbook*, Washington, DC.

Fuglie, K.O., and D.J. Bosch (1995). "Economic and Environmental Implications of Soil Nitrogen Testing," *American Journal of Agricultural Economics*: 77.

Gollehon, N., and D. Letson (1996). “Confined Animal Production and Manure Problem,” *CHOICES*, Third Quarter.

Hewitt, T.I.,W. Huang, and D. Shank (1994). “Timing Nitrogen Applications to Reduce Nitrogen Losses: How Much Will It Cost Farmers?” Paper presented at the Annual Meetings of the American Agricultural Association, San Diego, CA.

Hoeft, R.G. (1984). “Current Status of Nitrification Inhibitor Use in U.S. Agriculture,” *Nitrogen in Crop Production*. Soil Science Society of America, Madison WI.

Huang, Wen-yuan, and Stan G. Daberkow (1996). “The Role of Planting Flexibility and the Acreage Reduction Program in Encouraging Sustainable Agricultural Practices,” Journal of Sustainable Agriculture, Vol. 7(1): 63-79.

Huang, Wen-yuan, Russ W. Keim, Yao-chi Lu, and Terry Kelles (1996). “Evaluating Soil Nitrogen Testing Considering the Carryover Effect.” Paper presented at the 1996 AAEA annual meeting, San Antonio, TX, Aug. 27-31.

Huang, Wen-yuan, David Shank, and Tracy Irwin Hewitt (1996). “On-Farm Costs of Reducing Nitrogen on Cropland Vulnerable to Nitrate Leaching,” *Review of Agricultural Economics*, 18 (1996): 325-339.

Huang, Wen-yuan, and Harold Taylor (1996). “Use of Nitrogen Stabilizers in U.S. Crop Production and Economic and Environmental Effects.” Paper presented in 1996 Annual Meeting of Southern Agricultural Economics Association. Greensboro, NC, Feb.

Huang, W., N. Uri, and L. Hansen (1994). “Timing Nitrogen Fertilizer Applications to Improve Water Quality,” AGES9407. U.S. Dept. Agr., Econ. Res. Serv., Feb.

Huang, Wen-yuan, and Rhona M. Lantin (1993). “A Comparison of Farmers’ Compliance Costs to Reduce Excess Nitrogen Fertilizer Use Under Alternative Policy Options.” *Review of Agricultural Economics*, Vol. 15, No. 1, Jan.

Huang, Wen-yuan, and Michael LeBlanc (1994). “Market-Based Incentives for Addressing Non-Point Water Quality Problems: A Residual Nitrogen Tax Approach,” *Review of Agricultural Economics*, Vol. 16, No. 3, Sept.

Huang, Wen-yuan, Roger Selley, Agapi Somwaru, and David Westenbarger (1996). “Using Planting Flexibility Options To Improve Water Quality in the Central Nebraska Basins.” Unpublished report, U.S. Dept. Agr., Econ. Res. Serv., NRED.

Kanwar, R.S., J.L. Baker, and D.G. Baker (1988). "Tillage and Split N-Fertilizer Effects on Subsurface Drainage, Water Quality, and Crop Yields," *Transations of the American Society of Agricultural Engineers*, Vol. 31, March-April.

Lowenberg-DeBoer, J., and S. Swinton (1995). *Economics of Site-Specific Management in Agronomic Crops,* Staff Paper 95-62, Michigan State University, Department of Agricultural Economics, East Lansing, MI, Nov.

Meisinger, J. J. (1984). "Evaluating Plant-Available Nitrogen in Soil-Crop Systems," *Nitrogen in Crop Production*. Soil Science Society of America, Madison, WI.

Meisinger, J. J., and G. W. Randall (1991). "Estimating Nitrogen Budgets for Soil-Crop Systems." *Managing Nitrogen for Groundwater Quality and Farm Profitability*. Soil Science Society of America, Madison, WI.

Mengel, D.B. (1986). *Managing Nitrogen Fertilizers for Maximum Efficiency in Reduced Tillage Systems*. Cooperative Extension Service, Purdue University, West Lafayette, IN.

Mueller, D.K., P.A. Hamilton, D.R Helsel, K.J. Hitt, and B.C. Ruddy (1995). *Nutrients in Ground Water and Surface Water of the United States - An Analysis of Data Through 1992.* Water-Resources Investigations Report 95-4031. U.S. Geological Survey.

Nebraska Association of Resources Districts (1990). *Natural Resources Districts---Unique, Progressive Leadership in Conservation.*

Nelson, D. W., and D. Huber (1987). "Nitrification Inhibitors for Corn Production," *National Corn Handbook 55*. Purdue University Cooperative Extension Service.

Rhoads, F. M.(1991). "Nitrogen or Water Stress: Their Interrelationships." *Managing Nitrogen for Groundwater Quality and Farm Profitability*. Soil Science Society of America, Madison, WI.

Sander, D.H., D.T. Walters, and K.D. Frank (1994). “Nitrogen Testing for Optimum Management,” *Nutrient Management: A Supplement to the Journal of Soil and Water Conservation*, Vol. 49, No. 2.

Scharf, P. C., and M.M. Alley (1988). "Nitrogen Loss Pathways and Nitrogen Loss Inhibitors: A Review," *Journal of Fertilizer Issues*. Vol 5, No.4, Oct.-Dec.

Schlegel, A.J., and J.L. Havlin (1995). "Crop Response to Long-Term Nitrogen and Phosphorous Fertilization," *Journal of Production Agriculture*, Vol. 8, No. 2, April-June.

Shortle, J.S., W.N.Musser, W.C. Huang, B. Roach, K. Kreahling, D. Beegle, and R. M. Fox (1993). *Economics of Environmental Potential of the Pre-side-dressing*

Recent ERS Research on Nutrient Management

"On-farm Costs of Reducing Residual Nitrogen on Cropland Vulnerable to Nitrate Leaching," *Review of Agricultural Economics*, Vol. 18, No. 4, Sept. 1996 (Wen-yuan Huang, David Shank, and Tracy Irwin Hewitt). A farm-level dynamic model considering nitrogen carryover effects was used to analze the costs to a farmer of complying with a restriction on nitrogen fertilizer use on cropland vulnerable to nitrate leaching. While the theoretical results were indeterminate, empirical results from an Iowa case study indicated that a fertilizer use restriction on cropland highly vulnerable to leaching will have a smaller compliance cost than on cropland with a moderate leaching potential.

"Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices," *American Journal of Agricultural Economics*, Vol. 78, No.1, Feb. 1996 (Joseph C. Cooper and Russ W. Keim). This paper uses both a bivariate probit with sample selection model and a double hurdle model to predict the impacts of different incentive payments on farmer adoption of integrated pest management, legume crediting, manure tests, split applications of nitrogen, and soil moisture testing. The results can be used to aid decisions on how to allocate program budgets among the preferred production practices.

"Economic and Environmental Implications of Soil Nitrogen Testing: A Switching-Regression Analysis," *American Journal of Agricultural Economics*, Vol. 77, No. 4, Nov. 1995 (Keith O. Fuglie and Darrell J. Bosch). A simultaneous equations, or "switching-regression," model is developed to assess the impact of soil nitrogen (N) testing on N use, crop yields, and net returns in corn growing areas of Nebraska. The results indicate that when there is uncertainty about the quantity of available carryover N, testing for N enables farmers to reduce fertilizer use without affecting crop yields. However, the value of information from N tests depends critically on cropping history and soil characteristics.

"The Role of Planting Flexibility and the Acreage Reduction Program (ARP) in Encouraging Sustainable Agricultural Practices," *Journal of Sustainable Agriculture*, Vol. 7, No. 1, Sept. 1995 (Wen-yuan Huang and Stan G. Daberkow). This article examines the impact of increasing planting flexibility (P) on program participation, farm income, crop diversity, and government payments. For a representative western Corn Belt farm, increasing P to more than 63 percent with zero ARP would result in farmers being better off in switching from continuous corn to a corn-soybean rotation. However, increasing the P and reducing the ARP may sacrifice some environmental benefits.

Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution. AIB-716, May 1995 (Peter M. Feather and Joeph Cooper). This report examines the success of existing incentive programs in achieving adoption of manure crediting, legume crediting, split N application, irrigation scheduling, and deep soil nitrate testing. Results indicate large incentive payments may be necessary to achieve high adoption levels, and adoption rates differ both across practices and across geographic areas. Programs involving cost-sharing and incentive payments could be more successful if incentives were altered to account for these differences.

"Voluntary Versus Mandatory Agricultural Policies to Protect Water Quality: Adoption of Nitrogen Testing in Nebraska," *Review of Agricultural Economics*, Vol 17, No. 1 Jan. 1995. (Bosch, D. L., Z. L. Cook, and K.O. Fuglie). This article evaluates the effectiveness of regulation versus a combination of voluntary incentive approaches for increasing Nebraska farmers' use of soil and/or tissue testing on the fields planted to corn. The results indicate that while regulation leads to higher levels of N test adoption, it does not have an "educational" effect on adopters. Educational programs may be needed to complement regulations to ensure that farmers change their behavior to achieve the goals of water quality protection programs .

"Market-Based Incentives for Addressing Non-point Water Quality Problems: A Residual Nitrogen Tax Approach," *Review of Agricultural Economics*, Vol. 16, No. 4, Sept. 1994(Wen-yuan Huang and Michael LeBlanc). This study analyzes the implications of a tax scheme which would penalize farmers for applying nitrogen in excess of a crop's nitrogen uptake and reward them for growing crops that capture and utilize residual soil nitrogen. Corn production is used to illustrate the differential impacts of residual nitrogen tax on farm income in Corn Belt States.

--continued

Recent ERS Research on Nutrient Management (cont.)

An Economic Analysis of Agricultural Practices Related to Water Quality: the Ontario (Oregon) Hydrologic Unit Area. ERS Staff Report No. AGES-9418. June 1994 (C. S. Kim, Ronald Fleming, Richard M. Adams, Marshall English, and C. Sandretto). This report evaluates the effects of adopting Best Management Practices (BMPs) on groundwater quality in Ontario (Oregon) area by incorporating time lags associated with nitrate leaching and groundwater flow. Results indicate that Federal drinking water standard of no more 10 ppm nitrate in groundwater may be accomplished in 12 years by adopting improved irrigation systems such as auto-cutback systems or solid-set sprinkler systems. However, the adoption of both improved irrigation systems and nutrient management systems, such as side-dressing and ceasing fall fertilization, would be necessary to meet the strict Oregon drinking water standard of 7 ppm.

"The Role of Information in the Adoption of Best Management Practices for Water Quality Improvement." *Agricultural Economics*, No. 11 April 1994. (Peter M. Feather and Gregory S. Amacher). This paper tests the hypothesis that a lack of producer information regarding both the profitability and the environmental benefits of adopting improved practices may be a reason why widespread adoption of these practices has not occurred. A two-stage adoption model is specified and estimated using data from a survey of producers. The results indicate that producer perceptions play an important role in decision to adopt. Changing these perceptions by means of an educational program may be a reasonable alternative to financial incentives.

Timing Nitrogen Fertilizer Applications to Improve Water Quality. ERS Staff Report No. AGES-9407, February 1994 (Wen-yuan Huang, Noel D. Uri, and LeRoy Hansen). Analytical models are developed to determine the necessary conditions for the optimal timing of nitrogen fertilizer application. The empirical results explain various observed timings of nitrogen fertilizer application to cotton in Mississippi, and provide an estimate of a farmer's cost in complying with a restriction on the timing of nitrogen fertilizer application.

(Contact to obtain reports: Wen-yuan Huang, (202) 501-8289 [whuang@econ.ag.gov])

Soil Nitrate Test. Final Report to the Environmental Protection Agency. Department of Agricultural Economics and Rural Sociology, Pennsylvania State University.

Snyder, C., T. Schroeder, J. Havlin, and Kluitenberg (1997). "An Economic Analysis of Variable-Rate Nitrogen Management," in *Proceedings of the 3rd International Conference on Precision Agriculture*. June 23-26, 1996, Minneapolis, MN. Published by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

U.S. Department of Agriculture, National Agricultural Statistics Service (1996). *Agricultural Prices*.

U.S. Department of Agriculture, Natural Resources Conservation Service (1995a). *Nutrient Management for Better Crops, More Profit, and Clean Water*. Des Moines, Iowa.

__________ (1995b). *Third Resource Conservation Act Appraisal*. Draft.

__________ (1992). *Agricultural Waste Management Field Handbook*.

U.S. Environmental Protection Agency (1992). *Another Look: National Survey of Pesticides in Drinking Water Wells*, Phase II Report. EPA 579/09-91-020, Jan.

U.S. Environmental Protection Agency (1995). *National Water Quality Inventory: 1994 Report to Congress* Executive Summary. Dec.

Winrock International (1995). *Poultry Litter Marketing & Utilization Project: A Case Study 1992-1995, Creating Market Demand to Link and Resolve Two Environmental Problems*. May.

4.6. Irrigation Water Management

Water management is an important element of irrigated crop production. Efficient irrigation systems and water management practices can help maintain farm profitability in an era of limited, higher-cost water supplies. Efficient water management may also reduce the impact of irrigated production on offsite water quantity and quality. However, measures to increase water-use efficiency may not be sufficient to achieve environmental goals in the absence of other adjustments within the irrigated sector. As is often the case, technology is not the whole solution anywhere, but part of the solution almost everywhere.

Contents

The U.S. Department of Agriculture identifies improvements in water management as one of the primary agricultural policy objectives for the 1990's (USDA, 1994). Irrigation water management (IWM) involves the managed allocation of water and related inputs in irrigated crop production, such that economic returns are enhanced relative to available water. Conservation and allocation of limited water supplies is central to irrigation management decisions, whether at the field, farm, irrigation-district, or river-basin level.

Why Manage Irrigation Water?

Irrigation water is managed to conserve water supplies, to reduce water-quality impacts, and to improve producer net returns.

Water Conservation. Water savings through improved management of irrigation supplies are considered essential to meeting future water needs. Irrigation is the most significant use of water, accounting for over 95 percent of freshwater withdrawals consumed in several Western States and roughly 80 percent nationwide (see chapter 2.1, *Water Use and Pricing)*. However, expanding water demands for municipal, industrial, recreational, and environmental purposes increasingly compete for available water supplies. Since opportunities for large-scale water-supply development are limited, additional water demands must be met largely through conservation and reallocation of existing irrigation supplies (Moore, 1991; Schaible and others, 1991; Vaux, 1986; Howe, 1985).

Water Quality. Improved water management can also help minimize offsite water-quality impacts of irrigated production. Irrigated agriculture affects water quality in several ways, including higher chemical-use rates associated with irrigated crop production, increased field salinity and erosion due to applied water, accelerated pollutant transport with drainage flows, degradation due to increased deep percolation to saline formations, and greater instream pollutant concentrations due to reduced flows. Strategies to improve the Nation's water quality must address the effect of irrigation on surface and ground water bodies (National Research Council, 1996).

Farm Returns. Finally, improvements in IWM can help maintain the long-term viability of the irrigated agricultural sector. Irrigated cropland is important to the U.S. farm economy, accounting for about 40 percent of total crop sales with just 15 percent of the Nation's harvested cropland in 1992 (USDC, 1994). Water savings at the farm level can help offset the effect of rising water costs and restricted water supplies on producer income. Improved water management may also reduce expenditures for energy, chemicals, and labor inputs, while enhancing revenues through higher crop yields and improved crop quality.

Use of Improved Irrigation Technology and Management

How producers respond to higher water costs and limited water supplies is important to policymakers. Producers may reduce water use per acre by applying less than full crop-consumptive requirements (deficit irrigation), shifting to alternative crops or varieties of the same crop that use less water, or adopting more efficient irrigation technologies. In some cases, producers may convert from irrigated to dryland farming or retire land from production. Many irrigators have responded to water scarcity through the use of improved irrigation technologies—often in combination with other water-conserving strategies—and irrigators will likely look to technology as one of several means of conserving water in the future.

Various management practices and irrigation technologies are available to enhance efficiency of applied water in irrigated agriculture (see box, "Irrigation Water-Use Efficiency"). Irrigation improvements often involve upgrades in physical application systems, with improved field application efficiencies and higher yield potentials. Improved water management practices, such as irrigation scheduling and water-flow measurement, may also be required to achieve maximum potentials of the physical system. In addition, management of drainage flows may be an important concern in many irrigated areas (table 4.6.1). In some cases, the effectiveness of improved irrigation practices may be enhanced when implemented in combination with other farming practices such as conservation tillage and nutrient management.

Irrigation Water-Use Efficiency

Water-use efficiency measures are commonly used to characterize the water-conserving potential of irrigation systems. Alternative efficiency measures reflect various stages of water use and levels of spatial aggregation. **Irrigation efficiency**, broadly defined at the field level, is the ratio of the average depth of irrigation water beneficially used (consumptive use plus leaching requirement) to the average depth applied, expressed as a percentage. **Application efficiency** is the ratio of the average depth of irrigation water stored in the root zone for crop consumptive use to the average depth applied, expressed as a percentage. Crop-water consumption includes stored water used by the plant for transpiration and tissue building, plus incidental evaporation from plant and field surfaces. Leaching requirement, which accounts for the major difference between irrigation efficiency and application efficiency, is the quantity of water required to flush soil salts below the plant root zone. Field-level losses include surface runoff at the end of the field, deep percolation below the crop-root zone (not used for leaching), and excess evaporation from soil and water surfaces. **Conveyance efficiency** is the ratio of total water delivered to the total water diverted or pumped into an open channel or pipeline, expressed as a percentage. Conveyance efficiency may be computed at the farm, project, or basin level. Conveyance losses include evaporation, ditch seepage, operational spills, and water lost to noncrop vegetative consumption. **Project efficiency** is calculated based on onfarm irrigation efficiency and both on- and off-farm conveyance efficiency, and is adjusted for drainage reuse within the service area. Project efficiency may not consider all runoff and deep percolation a loss since some of the water may be available for reuse within the project.

Irrigation Application Systems

Irrigation application systems may be grouped under two broad system types: gravity flow and pressurized systems. (For an explanation of irrigation systems discussed here, see boxes, "Gravity (Pressurized) Irrigation Systems and Practices," pp. 229-230.)

Gravity-Flow Systems. Many irrigation systems rely on gravity to distribute water across the field. Land treatments—such as soil borders and furrows—are used to control lateral water movement and channel water flow down the field. Water is conveyed to the field by means of open ditches, above-ground pipe (including gated pipe), or underground pipe, and released along the upper end of the field through siphon tubes, ditch gates, or pipe valves. Fields are

Table 4.6.1—Irrigation technology and water management: conventional methods and improved practices

System and aspect	Conventional technology or management practice	Improved technology or management practice
Onfarm conveyance	Open earthen ditches.	Concrete or other ditch linings; above-ground pipe; below-ground pipe.
Gravity application systems:		
Release of water	Dirt or canvass checks with siphon tubes.	Ditch portals or gates; gated pipe; gated pipe with surge flow or cablegation.
Field runoff	Water allowed to move off field.	Applications controlled to avoid runoff; tailwater return systems.
Furrow management	Full furrow wetting; furrow bottoms uneven.	Alternate furrow wetting; furrow bottoms smooth and consistent.
Field gradient	Natural field slope, often substantial; uneven field surface.	Land leveled to reduce and smooth field surface gradient.
Length of irrigation run	Length of field, often 1/2 mile or more.	Shorter runs, 1/4 mile or less.
Pressurized application systems:		
Pressure requirements	High pressure, typically above 60 psi.	Reduced pressure requirements, often 10-30 psi.
Water distribution	Large water dispersal pattern.	More narrow water dispersal through sprinkler droptubes, improved emitter spacing, and low-flow systems.
Automation	Handmove systems; manually operated systems.	Self-propelled systems; computer control of water applications.
Versatility	Limited to specific crops; used only to apply irrigation water.	Multiple crops; various uses—irrigation, chemigation, manure application, frost protection, crop cooling.
Water management:		
Assessing crop needs	Judgment estimates.	Soil moisture monitoring; plant tissue monitoring; weather-based computations.
Timing of applied water	Fixed calendar schedule.	Water applied as needed by crop; managed for profit (not yield); managed for improved effectiveness of rainfall.
Measurement of water	Not metered.	Measured using canal flumes, weirs, and meters; external and inpipe flow meters.
Drainage	Runoff to surface-water system or evaporation ponds; percolation to aquifers.	Applications managed to limit drainage; reuse through tailwater pumpback; dual-use systems with subirrigation.

Source: USDA, ERS.

generally rectangular with water runs typically ranging from one-eighth to one-half mile in length. Gravity systems are best suited to medium- and fine-textured soils with higher moisture-holding capacities; field slope should be minimal and fairly uniform to permit controlled water advance.

Although total acreage in gravity systems has declined by 20 percent since 1979, gravity-flow systems still account for over half of irrigated acreage nationwide (table 4.6.2). Gravity-flow systems are used in all irrigated areas, and are particularly predominant in the Southwest (California, Nevada, Arizona, New Mexico), Central Rockies (Wyoming, Colorado, Utah), Southern Plains (Texas, Oklahoma), and Delta (Arkansas, Louisiana, Mississippi) regions. The predominance of gravity systems in arid regions of the West reflects early project development on broad, flat alluvial plains; high crop water-consumption requirements; and increased soil salt-

Table 4.6.2—Changes in irrigation system acreage, 1979-94

System	1979	1994	Change 1979-94
	Million acres		*Percent*
All systems	50.1	46.4	-7
Gravity-flow systems	31.2	25.1	-20
Sprinkler systems	18.4	21.5	17
Center pivot	8.6	14.8	72
Mechanical move	5.1	3.7	-27
Hand move	3.7	1.9	-48
Solid set and permanent	1.0	1.0	2
Low-flow irrigation (drip/trickle)	.3	1.8	445
Subirrigation	.2	.4	49

Source: USDA, ERS, based on USDC, 1982 and 1996.

Table 4.6.3—Irrigation application systems, by type, 1994

System	Acres	Share of all systems
	Million	*Percent*
All systems	46.4	100
Gravity flow systems	25.1	54
Row/furrow application	14.2	31
Open ditches	5.0	11
Above-ground pipe	7.4	16
Underground pipe	1.8	4
Border/basin application	7.5	16
Open ditches	5.1	11
Above-ground pipe	.9	2
Underground pipe	1.5	3
Uncontrolled flooding application	2.3	5
Open ditches	2.3	5
Above-ground pipe	.0	0
Underground pipe	.0	0
Sprinkler systems	21.5	46
Center pivot	14.8	32
High pressure	3.2	7
Medium pressure	5.9	13
Low pressure	5.7	12
Mechanical move	3.7	8
Linear and wheel-move	3.0	7
All other	.6	1
Hand move	1.9	4
Solid set & permanent	1.0	2
Low-flow irrigation (drip/trickle)	1.8	4
Subirrigation	.4	1

Note: Percents may not sum to totals due to multiple systems on some irrigated acres and rounding.
Source: USDA, ERS, based on USDC, 1996.

leaching requirements. Furrow application systems comprise nearly 60 percent of all gravity-flow systems; border/basin and uncontrolled-flood application systems account for the remaining acreage (table 4.6.3).

Water losses are comparatively high under traditional gravity-flow systems due to percolation losses below the crop-root zone and water runoff at the end of the field. Field application efficiencies typically range from 40 to 65 percent, although improved systems with proper management may achieve efficiencies of up to 85 percent (Negri and Hanchar, 1989).

Various land treatment and management measures have been developed to reduce water losses under gravity-flow systems (table 4.6.1). Measures include improved onfarm water-conveyance systems, precision field leveling, shortened water runs, alternate furrow irrigation, surge flow and cablegation, and tailwater reuse.

Improved water-conveyance systems are an important potential source of farm-level water savings. System upgrades include ditchlining, ditch reorganization, and pipeline installation. According to the 1994 Farm and Ranch Irrigation Survey (FRIS), traditional open-ditch systems remain the principal means of onfarm water conveyance for gravity-flow systems, with almost 60 percent of gravity-acreage served (USDC, 1996). Above-ground pipelines—including gated pipe—accounted for a third of gravity-flow acreage served, with underground lines serving the remaining acreage.

Improvements in traditional gravity technology can increase the uniformity of applied water, while reducing percolation losses and minimizing water runoff. Gated-pipe systems are concentrated in the Northern and Southern Plains and Delta regions. Surge-flow and cablegation systems—designed to control water deliveries from gated pipe—are used on 5 percent of gravity-flow acreage, predominantly in

Gravity Irrigation Systems and Practices

Open-ditch conveyance systems have been the traditional means to supplying gravity irrigation systems. Open ditches may be earthen, although improved systems are typically lined with concrete or other less permeable materials to reduce seepage loss. Water is delivered to gravity-flow fields through siphon tubes, portals, or ditch gates.

Furrow systems, the dominant gravity application system, are distinguished by small, shallow channels used to guide water downslope across the field. Furrows are generally straight, although they may be curved to follow the land contour on steeply sloping fields. Row crops are typically grown on the ridge or bed between the furrows, spaced from 2 to 4 feet apart. Corrugations—or small, closely spaced furrows—may be used for close-growing field crops.

Border (or flood) application systems divide the field into strips, separated by parallel ridges. Water flows downslope as a sheet, guided by ridges 10 to 100 feet apart. On steeply sloping lands, ridges are more closely spaced and may be curved to follow the land contour. Border systems are suited to orchards and vineyards, and close-growing field crops such as alfalfa, pasture, and small grains.

Uncontrolled flooding is a gravity-flood system without constructed ridges, relying on natural slope to distribute water.

Improved System and Practices:

Pipeline conveyance systems are often installed to reduce labor and maintenance costs, as well as water losses to seepage, evaporation, spills, and noncrop vegetative consumption. ***Underground pipeline*** constructed of steel, plastic, or concrete is permanently installed; ***above-ground pipeline*** generally consists of lightweight, portable aluminum, plastic, or flexible rubber-based hose. One form of above-ground pipeline—***gated-pipe***—distributes water to gravity-flow systems from individual gates (valves) along the pipe.

Field leveling involves grading and earthmoving to eliminate variation in field gradient—smoothing the field surface and often reducing field slope. Field leveling helps to control water advance and improve uniformity of soil saturation under gravity-flow systems. Precision leveling is generally undertaken with a laser-guided system.

Level basin systems differ from traditional border application systems in that field slope is level and field ends are closed. Water is applied at high volumes to achieve an even, rapid ponding of the desired application depth within basins. Higher application efficiencies reflect uniform infiltration rates and elimination of surface runoff.

Shortened water runs reduce the length of furrow (or basin) to increase uniformity of applied water across the field. Reduced water runs are most effective on coarse soils with high soil-water infiltration rates. Water runs of one-half to one mile in length may be reduced to one-quarter mile or less (with reorganization of the onfarm conveyance system).

Surge flow is an adaptation of gated-pipe systems in which water is delivered to the furrow in timed releases. Initial water surges travel partway down the furrow, and all standing water is allowed to infiltrate. The wetted soil surface forms a water seal permitting successive surges to travel further down the furrow with less upslope deep percolation. This technique significantly reduces the time needed for water to be distributed the full length of the field, thereby increasing application efficiency.

Cablegation is a gated-pipe system in which a moveable plug passes slowly through a long section of gated pipe, with the rate of movement controlled by a cable and brake. Due to the oversizing and required slope of the pipe, water will gradually cease flowing into the first rows irrigated as the plug progresses down the pipe. Improved water management is achieved by varying the speed of the plug, which controls the timing of water flows into each furrow.

Alternate furrow irrigation involves wetting every second furrow only. This technique limits deep percolation losses by encouraging lateral moisture movement. Applied water and time required per irrigation may be significantly less than under full furrow systems, but more irrigations may be required to supply crop needs. This technique is very effective when the desired strategy is to irrigate to a “less than field capacity” level in order to more fully utilize rainfall.

Special furrows have been employed to enhance water management. ***Wide-spaced furrows*** function much like alternative furrow irrigation, except that every row is irrigated with rows spaced further apart. ***Compacted furrows*** involve packing the soil within the furrow to provide a smooth, firm surface to speed water advance. ***Furrow diking*** places dikes in the furrows to capture additional rainfall, eliminating runoff and reducing irrigation needs. Furrow diking on gravity-irrigated fields is typically used in combination with alternate furrow irrigation.

Tailwater reuse systems recover irrigation runoff in pits below the field and pump it to the head of the field for reuse.

Pressurized Irrigation Systems and Practices

Pipeline conveyance is most often used to deliver water to fields with pressurized systems. Water, once under pressure, requires a pipeline for conveyance. Pipelines may be above or below ground.

Center-pivot sprinklers are the dominant pressure technology. A center-pivot sprinkler is a self-propelled system in which a single pipeline supported by a row of mobile A-frame towers is suspended 6 to 12 feet above the field. Water is pumped into the pipe at the center of the field as towers rotate slowly around the pivot point, irrigating a large circular area. Sprinkler nozzles mounted on or suspended from the pipeline distribute water under pressure as the pipeline rotates. The nozzles are graduated small to large so that the faster moving outer circle receives the same amount of water as the slower moving inside. Typical center-pivot sprinklers are one-quarter mile long and irrigate 128- to 132-acre circular fields. Center pivots have proven to be very flexible and can accommodate a variety of crops, soils, and topography with minimal modification.

Hand move is a portable sprinkler system in which lightweight pipeline sections are moved manually for successive irrigation sets of 40 to 60 feet. Lateral pipelines are connected to a mainline, which may be portable or buried. Handmove systems are often used for small, irregular fields. Handmove systems are not suited to tall-growing field crops due to difficulty in repositioning laterals. Labor requirements are higher than for all other sprinklers.

Solid set refers to a stationary sprinkler system. Water-supply pipelines are generally fixed—usually below the soil surface—with sprinkler nozzles elevated above the surface. In some cases, handmove systems may be installed prior to the crop season and removed at or after harvest, effectively serving as solid set. Solid-set systems are commonly used in orchards and vineyards for frost protection and crop cooling, and are widely used in turf production and landscaping.

Big gun systems use a large sprinkler mounted on a wheeled cart or trailer, fed by a flexible hose. The sprinkler is usually self-propelled while applying water. The system may require successive moves to irrigate the field. Big guns require high operating pressures, with 100 psi not uncommon. These systems have been adapted to spread livestock waste in many locations.

Side-roll wheel-move systems have large-diameter wheels mounted on a pipeline, enabling the line to be rolled as a unit to successive positions across the field. A gasoline engine generally powers the system movement. This system is roughly analogous to a handmove system on wheels. Crop type is an important consideration for this system since the pipeline is roughly 3 feet above the ground.

Improved Systems and Practices:

Improved center pivots have been developed that reduce both water application losses and energy requirements. Older center pivots, with the sprinklers attached directly to the pipe, operate at relatively high pressure (60-80 psi), with wide water-spray patterns. Newer center pivots usually locate the sprinklers on tubes below the pipe and operate at lower pressures (15-45 psi). Many existing center pivots have been retrofitted with system innovations to reduce water losses and energy needs.

Linear or ***lateral-move*** systems are similar to center-pivot systems, except that the lateral line and towers move in a continuous straight path across a rectangular field. Water may be supplied by a flexible hose or pressurized from a concrete-lined ditch along the field edge.

LEPA (Low-energy precision application) is an adaptation of center pivot (or lateral-move) systems that uses droptubes extending down from the pipeline to apply water at low pressure below the plant canopy, usually only a few inches above the ground. Applying water close to the ground cuts water loss from evaporation and wind and increases application uniformity. On soils with slower infiltration rates, furrow dikes are often used to avoid runoff.

Low-flow irrigation systems include ***drip/trickle*** and ***micro-sprinkler*** systems. ***Drip and trickle*** systems use small-diameter tubes placed on or below the field's surface. Frequent, slow applications of water are applied to soil through small holes or emitters. The emitters are supplied by a network of main, submain, and lateral lines. Water is dispensed directly to the root zone, precluding runoff or deep percolation and minimizing evaporation.
Micro-sprinklers use a similar supply system, with low-volume sprinkler heads located about 1 foot above the ground. (Micro-sprinklers are used in place of multiple drip emitters when wetting a broader area or perimeter.) Low-flow systems are generally reserved for perennial crops, such as orchard products and vineyards, or high-valued vegetable crops.

the Plains States. Alternate furrow irrigation is practiced on over 20 percent of gravity-flow acres, with special furrows (widespaced, compacted, or diked) applied on more than 10 percent of acres. Roughly 5 percent of FRIS respondents indicated that water runs had been shortened to facilitate water management, primarily in the Southwest (Arizona, California) and Southern Plains. About 12 percent of all irrigated acres have been precision laser-leveled, predominantly on gravity-flow systems in the Southwest, Delta, and Southeast regions. High-efficiency level-basin systems are concentrated in the Southwest. Deficit irrigation techniques—such as reduced irrigation set-times, partial-field irrigation, and reduced irrigations—are practiced on roughly 10 percent of gravity-flow acres, with highest acreage concentrations in the Northwest (Washington, Oregon, Idaho). Tailwater reuse systems—which recirculate runoff water on the field—have been installed on over 20 percent of gravity-system acreage nationwide. Tailwater reuse systems are disbursed throughout the major gravity-irrigated States, with California leading both in total acreage (1.9 million) and share of gravity acres (38 percent) with tailwater systems.

Pressurized Systems. The decline in gravity-flow acreage has been accompanied by an increase in acreage under pressurized systems. Pressurized systems—including sprinkler and low-flow irrigation systems—use pressure to distribute water. With rare exceptions, the pressure to distribute water involves pumping, which requires energy. Acreage in pressurized systems expanded from 19 million acres (37 percent of total irrigated acreage) in 1979 to 23 million acres (50 percent) in 1994 (table 4.6.2).

Sprinkler systems—in which water is sprayed over the field surface, usually from above-ground piping—accounted for 46 percent of irrigated acreage in 1994 (table 4.6.3). Concentrations of sprinkler acreage are highest in the Northern Pacific, Northern Plains, and Northern Mountain States. Sprinkler systems are also used extensively for supplemental irrigation and specialty-crop irrigation in the humid eastern States.

Sprinkler irrigation has been adopted in many areas as a water-conserving alternative to gravity-flow systems. Field application efficiencies typically range from 60 to 85 percent under proper management (Negri and Hanchar, 1989). Sprinklers may be operated on moderately sloping or rolling terrain unsuited to gravity systems, and are well suited to coarser soils with higher water infiltration rates. Sprinkler design is important, and careful consideration of soil type, wetting area per spray nozzle, operating pressure, and the rate of sprinkler movement are required to avoid plant stress from too little water and excess runoff from too much water.

Capital costs for sprinkler systems are higher than for gravity-flow systems, although gravity-system installation often requires greater expenditures for land preparation. Operating costs for sprinkler systems are often higher than for gravity systems as they require more energy and more sophisticated technical and management capability. Labor costs are typically lower under sprinkler systems, particularly with self-propelled systems.

Sprinkler technologies include a wide range of adaptations, with significant shifts in technology shares in recent years. The development of self-propelled center-pivot systems in the 1960's greatly expanded the acreage suitable for irrigation, and accounted for much of the growth in acreage irrigated during the 1970's. Acres irrigated with center pivots increased by 6.2 million acres from 1979 to 1994, with about half of the increase attributable to net increases in irrigated area under sprinkler and about half from the net replacement of other sprinkler types with center pivot (table 4.6.2). Center-pivot systems accounted for nearly 70 percent of sprinkler acreage in 1994, or 32 percent of total irrigated acreage (table 4.6.3). Largest acreage concentrations under center-pivot are in the Northern Plains, Southern Plains, and Delta regions.

Sprinkler systems other than center pivot—including hand move, mechanical move, and solid set—made up about 31 percent of total sprinkler acreage in 1994, down from 53 percent in 1979. Acreage in handmove systems has declined by nearly one-half since 1979; mechanical-move systems have declined by more than 25 percent (table 4.6.2).

Center-pivot technology serves as the foundation for many technological innovations—such as low-pressure center pivot, linear-move, and low-energy precision application (LEPA) systems—which combine high application efficiencies with reduced energy and labor requirements. Approximately 40 percent of center pivot acres in 1994 were operated under low pressure (below 30 pounds per square inch (psi)), with just 22 percent operating at high pressure (above 60 psi). (Forty-two percent of center pivot acres were high-pressure systems as recently as 1988.) Adoption of low-pressure systems has been particularly strong in the Southern Plains, reflecting higher-cost groundwater pumping in much of the region. Current advances in sprinkler technology focus on location of spray heads and low-pressure sprinklers and nozzles; the trend is toward energy- and water-conserving nozzles located closer to the soil. In addition, advances are being made in remote control of sprinklers and individual nozzle control for precision agriculture.

Low-flow irrigation systems are a form of pressurized system in which water is applied in small, controlled quantities near or below ground level. Low-flow irrigation systems—including drip, trickle, and micro-sprinklers—comprise 4 percent of irrigated cropland acreage (table 4.6.3), up more than four-fold since 1979 (table 4.6.2). Low-flow systems are most commonly used for production of vegetables and perennial crops such as orchards and vineyards, although experimentation and limited commercial applications are occurring with certain row and field crops. Low-flow irrigation systems are located primarily in California and Florida, reflecting large acreages in specialty produce and orchard production.

Field application efficiency of 95 percent or greater can be achieved under low-flow systems, although proper design is required to avoid moisture stress and soil-salinity accumulation. High capital costs and short lifespan of components characterize most systems. Filtration of the water supply and careful system maintenance may be required to prevent clogging of small orifices. Advances in low-flow technology focus on field depth and spacing of tubing, emitter spacing, durability of materials, and reduced costs.

Water Management Practices

Determining when and how much irrigation water to apply is an important part of the irrigation management process. Well-informed decisions increase the likelihood that water is applied according to crop needs, with minimal water loss. Improved management practices are often more cost-effective than structural improvements, although structural upgrades may be required to achieve highest management potential.

Irrigation scheduling involves the application of irrigation water based on a systematic monitoring of crop soil-moisture requirements. Sophisticated scheduling methods—based on sensors, microprocessors, and computer-aided decision tools—may be used to determine the optimal timing and depth of irrigation to meet changing crop needs over the production season.

Various methods are available to assess crop water needs. Crop water requirements can be indirectly estimated through climate variables. Local weather-station data—including temperature, humidity, wind speed, and solar radiation—are applied in formulas to calculate crop water needs for a wide range of crops and locales. Soil moisture available for plant growth may also be measured directly through periodic soil testing. Soil probes are used to obtain soil samples at various depths for “feel and visual” evaluation. More sophisticated devices—such as tensiometers, neutron probes, and various electrical conductivity devices—can be used to accurately quantify the amount of water removed from the soil profile. Finally, plant moisture monitors may be used to detect crop water availability and stress in plant tissue.

In separate Farm and Ranch Surveys for years 1984 and 1994, irrigators were asked to indicate all methods used in deciding when to irrigate (USDC, 1986 and 1996). Survey results suggest that a slightly larger share of irrigators are using advanced, information-intensive methods to schedule irrigation, but that current levels indicate potential for much improvement. In the 1994 FRIS, 10 percent of irrigators used soil moisture-sensing devices (up from 8 percent in 1984), 5 percent used commercial scheduling (up from 3 percent), 4 percent used media reports on plant water requirements (down 1 percent), and 2 percent used computer simulations (not asked in 1984).

Water flow measurement is an important component of water management at the farm level. Measurement of water flows through the onfarm conveyance system ensures optimal water deliveries to the field, as determined by irrigation scheduling methods. Measuring devices—often installed in conjunction with conveyance system upgrades—include weirs, flumes, and in-canal flow meters for open ditches, and external and internal meters for pipe.

Irrigation Drainage Systems

The collection and disposal of drainage flows from irrigation and precipitation is an important management consideration in many irrigated areas. Irrigation drainage includes surface runoff and deep percolation from water applied to meet crop consumptive needs. In some areas, periodic flooding of fields may also be required to leach soil salts from the crop root zone, often increasing the need for drainage systems.

Irrigation drainage is often collected and reused in irrigated production. Tailwater systems recover drainage flows below the field (or in low-lying areas of the farm), recirculating the water to the top of the field for reuse. Drainage flows may also be used as irrigation supplies downslope, both onfarm and off-farm. In some cases, drainage systems may be used to drain excess water during wet periods as well as “subirrigate” during dry periods by regulating underlying water tables. In many cases, drainage flows of poor quality become a disposal issue. Primary disposal methods include onfarm evaporation ponds, direct discharge to off-farm surface water bodies through drainage canals, and reuse in salt-tolerant crop and tree production.

Other Practices Affecting Irrigation

Other practices—while not water-management practices *per se*—can be important components of an irrigated farming system. Such practices, in combination with improved irrigation systems, may enhance returns to irrigated production while reducing offsite environmental impacts.

Nutrient and Pest Management. Irrigation affects the optimal timing and application rate of chemical applications for nutrient and pest management. Fertilizer use is typically greater for high-valued, high-yielding irrigated production. Weed and pest conditions may also increase under irrigated field conditions, necessitating increased use of pesticides, herbicides, and fungicides. Careful nutrient and pest management increases the effectiveness of water and applied chemicals, while reducing offsite impacts.

Chemigation—or the application of fertilizers, pesticides, and other chemicals through irrigation water—permits controlled applications when used in conjunction with highly efficient irrigation systems. Chemigation can reduce the costs of applying chemicals, while avoiding equipment use and soil compaction. Chemigation is used on all major crops, with the largest treated acreages in orchard crops, hay, and corn—and the greatest concentration of use in potato, rice, and sugarbeet production (USDC, 1996).

Erosion Control. Soil erosion can be a serious problem for less efficient irrigation systems on sloping fields. Soil erosion creates barriers to even water flow in furrows, reduces long-term field productivity, and contributes to offsite water-quality problems. Irrigation-induced erosion is particularly severe in areas of the Northern Pacific, Southern Pacific, and Mountain regions (USDA, 1992).

Measures to improve uniformity of applied irrigation water can help control soil loss. Gravity-flow systems may be modified to reduce flow velocity or field slope in accordance with soil-water infiltration rates. Soil erosion may also be a problem with sprinkler systems, particular on steeply sloping fields and under outer spans of center-pivot systems where water application rates are higher. System adjustments to reduce erosion include reduced water applications per irrigation set, larger pattern sprinkler heads, and booms to increase sprinkler head spacing.

Other practices may also limit soil erosion on irrigated fields. Crop residue management to maintain vegetative material on the soil surface increases infiltration while protecting the soil from erosive water flow. In some cases, deep tillage can reduce runoff through increased infiltration. Land treatment measures may be installed to slow runoff and trap sediment on the farm. These include furrow dikes in the field, vegetative filter strips below the field, mini-basins in tailwater ditches, larger sediment ponds constructed in drainage ditches, and tailwater reuse systems.

A promising new soil amendment—Polyacrylamide, more commonly known as PAM—may be added to irrigation water to stabilize soil and water-borne sediment. Under experimental field-trial conditions, proper application of PAM with the first irrigation has substantially reduced soil erosion in furrow systems. Potential benefits include reduced topsoil loss, enhanced water infiltration, improved uptake of nutrients and pesticides, reduced furrow-reshaping operations, and reduced sediment-control requirements below the field. An estimated 50,000 irrigated acres were treated with PAM after just 1 year on the market, including 30,000 acres in the Pacific Northwest. Research is underway to determine the best PAM formulations and application techniques (Sojka and Lentz, 1996).

Irrigation Technology and Environmental Benefits

Adoption of improved irrigation technology has been advanced as a means to reduce offsite water quantity and quality problems. The effectiveness of technology in achieving environmental goals has important implications for regional water policy.

Water Conservation

Improved irrigation and conveyance technologies may substantially increase onfarm water-use efficiency. Whether technology adoption can achieve significant

Table 4.6.4—Irrigation water conservation for alternative crop-water consumptive requirements and field application efficiencies

Hypothetical crop	Consumptive water use	Application efficiency	Irrigation water applied	Application losses
	Inches	*Percent*	*Inches*	
Low water need	12	40	30	18
	12	60	20	8
	12	80	15	3
	12	100	12	0
High water need	24	40	60	36
	24	60	40	16
	24	80	30	6
	24	100	24	0

Source: USDA, ERS.

water savings for nonfarm and instream uses, however, will depend on many factors.

In general, a given percentage increase in field application efficiency will yield a less-than-proportional reduction in applied water. For example, a 50-percent increase in field application efficiency—from 40 percent to 60 percent—may reduce applied water by one-third (table 4.6.4). Actual quantities of water savings depend in part on the crop irrigated; the more water a crop requires, the greater the potential water savings through improved water management. Water savings also reflect the initial condition of the irrigation system.

Improvements in inefficient systems may result in substantial water savings, often at relatively low cost. Under more efficient systems, a comparable increase in efficiency results in lower water savings at a higher cost. For example, an increase from 40 to 60 percent in field application efficiency will yield greater water savings than an increase from 60 to 80 percent for the same crop (table 4.6.4). The increase from 40 to 60 percent can generally be achieved at lower cost through less expensive system modifications and management adjustments. As the target field application efficiency increases, there are fewer, more expensive technologies and management practices available to achieve the additional water savings.

Water withdrawn for irrigation purposes is either consumed in a beneficial or nonbeneficial use, or accounted for as nonconsumptive use—evaporation, field runoff, and deep percolation. Of the possible dispositions of irrigation withdrawals shown in table 4.6.5, water consumptively used to grow crops is represented by cell 1. Leaching applications for soil salinity control (cells 3, 5) represent a nonconsumptive, beneficial use. Irrigation efficiency at the field level reflects the share of applied water (cells 1 through 6) attributed to beneficial uses (cells 1, 3, 5). Historically, measures to increase irrigation efficiency have focused on reducing nonbeneficial irrigation-system losses (cells 2, 4, 6), without adequately considering the effect on drainage return flows and consumptive use.

Improved irrigation efficiency reduces nonbeneficial water losses (cells 2, 4, 6), which may be either reusable or nonreusable. Reductions in nonreusable field loss (cells 2, 4) under improved systems

Table 4.6.5—Use and disposition of irrigation withdrawals

	Consumptive use	Nonconsumptive use	
	Nonreusable	Nonreusable portion	Reusable portion
Beneficial uses	Cell #1: Crop evapotranspiration	Cell #3: Nonreusable deep percolation for salt leaching due to quality impairment	Cell #5: Reusable deep percolation for salt leaching
Nonbeneficial uses	Cell #2: Noncrop evapotranspiration and evaporation from sprinklers, open water, and excess wet soil area	Cell #4: Nonreusable runoff and excess deep percolation due to quality impairment	Cell #6: Reusable runoff and excess deep percolation

Source: USDA, ERS, based on Allen and others, 1996.

contribute directly to reduced water demand. However, reductions in reusable field loss (cell 6) may not translate into water savings. Reusable field loss—including surface-water return flow and aquifer recharge—represents an important water source for downstream withdrawals and environmental purposes in many locations. The portion of applied irrigation water that re-enters the hydrologic system as downstream water supply varies greatly depending on physical, hydrologic, and topographic factors. Further, reusable supply does not necessarily imply the water is immediately available. Runoff and subsurface flows may be discharged downstream of the need area while temporal lags in transporting runoff and recharge to useable water sources may be measured in months, years, or decades.

Efforts to increase irrigation efficiency can *directly* affect crop consumptive use (cell 1) in two ways. First, the greater uniformity of applied water associated with many improved technologies may result in higher crop yields, with resulting increases in consumptive water requirements. That is, the water "saved" through improved efficiency is used to augment crop yield on the same field. Second, if consumptive water use (and crop yield) per acre remains constant, water "saved" through improved efficiency may be used on other irrigated lands—both onfarm and across farms—subject to conveyance and legal restrictions. Improved irrigation efficiency can also affect consumptive use *indirectly* by altering land and water opportunity values across crops. Changes in relative values may prompt substitution among land, water, management, and other inputs; resultant changes in cropping patterns and onfarm water use can involve substantial shifts in water applied at the regional level.

While opportunities exist to increase water-use efficiency in irrigated agriculture, the quantity of "new" water acquired through reduced irrigation losses will depend on various factors. The effectiveness of onfarm improvements in augmenting water flows for instream and nonfarm uses may be limited by increased consumptive water use from expanded onfarm production, reduced irrigation return flows to surface-water systems, and limits on efficiency gains due to widespread irrigation improvements already in place. In addition, the availability and use of conserved water offsite depends on the physical storage and delivery system, the structure of water rights, and the availability of water to satisfy all claims. Where "saved" flows are available as increased non-reserved flows, and junior water-right holders receive only partial entitlements, water conserved upstream may be claimed by downstream irrigation interests. Unintended environmental impacts that can accompany improved efficiencies—such as reductions in downstream wetland habitat, reduced groundwater recharge, and modified stream return-flow—may be a concern in some areas.

Conservation efforts based on improved irrigation efficiency alone may need to be broadened to meet emerging water demands. Net water savings at the sub-basin level may require reductions in both consumptive use and nonreusable, nonconsumptive losses (shaded area of table 4.6.5, cells 1 through 4). Policies to reduce water demand may need to target reductions in crop consumptive use—through improved crop varieties, crop substitution, deficit irrigation, and acreage reductions. Assessment of nonreusable drainage loss and nonbeneficial consumptive use is site-specific and often difficult to quantify, but may be an important source of water savings in some areas. In addition, the reusable portion of irrigation applications (cells 5 and 6) should also be examined for conservation potential, recognizing spatial and temporal effects on surface and subsurface drainage flows. If the policy goal is to provide water for downstream urban and environmental uses, an effective conservation program may require reform of water rights and regulations to ensure allocation of conserved water for the desired purpose.

Various ERS-supported research has examined the effects of irrigation water policy on water use and conservation. Significant water savings are more likely to be observed at the extensive margin—through changes in irrigated land base and acreage by crop—rather than through adjustments in per-acre water applications (Moore and others, 1994). While limited water savings can often be achieved through lower-cost efficiency gains, more significant water savings generally require reductions in consumptive use—with implications for producer profit (Bernardo and Whittlesey, 1989). In addition, substitutions among crops and inputs can result in significant regional water savings (Schaible and others, 1995; Moore and others, 1994; Bernardo and Whittlesey, 1989). Schaible and others (1995) found that improvements in onfarm water-use efficiency increased the level of regional water savings attributable to crop substitution. A mix of conservation policies may help to distribute the costs of water conservation across water users and regions (Schaible and others, 1995).

Water Quality

Several ERS studies have addressed the effect of water-conserving technology on water quality. Findings suggest that onfarm technologies can have important water-quality impacts, although benefits are sensitive to the type of practice and the attributes and uses of collecting water bodies.

Research findings on nitrate contamination of ground water in eastern Oregon (Kim and others, 1994) and south-central Nebraska (Magleby and others, 1995) indicate the beneficial effect of technology adoption on water quality. However, the ability to affect water quality through improved irrigation technology depends, in part, on underlying aquifer conditions, including the depth to water table and rates of groundwater flows.

Research findings on sediment control in south-central Idaho (Magleby and others, 1989) suggest that irrigation practices can help to reduce sediment loadings in collecting streams. Environmental benefits may vary significantly across irrigation investment categories, however, with highest potential returns to non-structural water management practices. The effectiveness of improved irrigation practices in achieving water-quality benefits may be enhanced when implemented in combination with other conservation practices, such as conservation tillage and filter strips.

Polices to improve water quality may need to target both high-priority areas and cost-effective conservation practices in a whole-farm context. In many cases, improved water quality can be an important joint product with water conservation. Together, the combined benefits of increased onfarm efficiency may justify improved technologies, and may help to speed adoption at a rate greater than water savings alone can justify.

Factors Affecting Technology Adoption

The choice of irrigation technology is highly site-specific, reflecting locational, technical, and market factors. Field characteristics—such as field size and shape, field gradient, and soil type—are perhaps the most important physical considerations in selecting an irrigation system. Other important factors include technology cost (useful life, financing options); water supply characteristics (cost, quality, reliability, flow rate); crop characteristics (spacing, height); climate (precipitation, temperature, wind velocity); market factors (crop prices; energy cost, labor supply); producer characteristics (farming traditions, management expertise, risk aversion, tenant/owner status, commitment to farming); and regulatory provisions (groundwater pumping restrictions, drainage discharge limits, water transfer provisions). In many cases, current technology choice is limited by fixed investments in existing systems at the site.

The 1994 FRIS reports that 38 percent of farms made system improvements from 1990 to 1994, while no improvements were reported on 56 percent of farms. Those farms reporting improvements tended to be larger, accounting for 58 percent of the irrigated acres. Potential benefits of improved irrigation reflect, in part, the rate of technology adoption. FRIS collected information on several key factors affecting technology adoption, including capital requirements, technology information, water-pricing policy, and water-supply considerations.

Capital Requirements

Improvements in irrigation systems are often highly capital-intensive. FRIS reports that investment in onfarm irrigation equipment, facilities, and land improvements totaled $800 million in 1994, or nearly $10,000 per farm reporting expenditures (USDC, 1996). Capital expenditures included $573 million for irrigation equipment and machinery, $92 million for construction and deepening of wells, $82 million for permanent storage and distribution systems, and $51 million for land clearing and leveling. Replacement of existing systems accounted for the largest share of irrigation capital expenditures (64 percent), followed by irrigation expansion (19 percent) and conservation improvements (17 percent).

While improved irrigation technologies are often economically profitable in a long-run farm plan, high capital outlays may limit their adoption. FRIS reports that nearly 30 percent of respondents indicated that installation of improved practices was either too expensive or could not be financed (USDC, 1996). Smaller farms were less likely to invest in improvements, reflecting more limited financial resources and difficulties in adapting some types of improved systems to smaller fields.

Technology Information

Lack of information on the availability, use, and profitability of improved irrigation technologies may limit adoption rates. Improved technologies are less familiar and often more sophisticated than traditional practices, requiring additional technical and management expertise. In some cases, improved irrigation systems may necessitate changes in current farming practices and equipment complements. For many producers, the benefits of new technologies are uncertain. Of farmers reporting no system improvements over 1990-94, 74 percent were unaware of improvements that "fit" their operation (explained in part by insufficient information), while 20 percent indicated heightened production risk as a contributing factor (USDC, 1996).

Water Cost

Limited cost savings for water conservation reduce incentives to adopt improved irrigation practices. Limited cost-savings reflect low purchased-water prices and, in some cases, low energy expenditures for pumping and pressurization. In some cases, the cost of irrigation water is substantially less than both the value of water to producers and the opportunity costs of water in nonfarm uses. (For more discussion of water sources and cost, see chapter 2.1, *Water Use and Pricing.*)

Prices paid for off-farm surface-water supplies averaged $16 per acre-foot, or $36/acre, in 1994 (USDC, 1996). Surface-water prices are generally based on operation and maintenance costs of the delivery system. Deliveries are often charged on a fixed rate per irrigated acre, and are not necessarily adjusted for reduced water demand with improved management. Groundwater costs are generally limited to the cost of access—variable and fixed cost of pumping—and vary greatly depending on well yield, pumplift, power source, and other factors. In areas with significant groundwater pumplifts or high-cost surface water, water cost is an incentive to adopt conserving technologies.

According to the 1994 FRIS, irrigators recognize the benefits of conservation since only 6 percent of survey respondents reported that water-conserving practices have no economic benefit. Adoption incentives are greatest for producers relying on high-cost water supplies; producers using low-cost ground- and surface-water are less apt to invest in improved technologies (Caswell and Zilberman, 1985; Negri and Brooks, 1990).

Water Supply

The off-farm water storage and delivery system may limit improvements in irrigation management at the farm-level. High onfarm water-use efficiency depends on adequate and timely supplies of water. This requires a flexible surface-water system with sufficient off-farm storage and conveyance capacity, and effective control facilities and operating policies. Many older conveyance systems cannot be adapted to delivering water on demand without capital improvements. Limited off-farm water storage may further restrict water deliveries. Coordination is needed between the off-farm conveyance system and onfarm irrigation system to ensure compatible design and water-scheduling procedures.

Uncertainty of water supplies is an additional limiting factor. Surface-water supplies for junior water-right holders often vary significantly with water storage conditions and other factors. Producers may apply excessive water during peak-flow periods in an attempt to buffer the effects of potential late-season shortages. Variable water supplies may also restrict investment in more efficient structural system improvements, while favoring the use of portable systems and development of supplemental groundwater supplies. Risk of loss of future water rights further limits incentives to invest in water-conserving technologies. Of those irrigators responding to the question on barriers to adoption, almost 20 percent indicated that future water rights was a critical concern (USDC, 1996). Not surprisingly, the greatest concentration of farmers with this concern are in States with growing urban and environmental demands—California, Idaho, Texas, Nebraska, Colorado, Oregon, Washington, Utah, and Florida.

Policies and Programs Promoting Improved Irrigation Water Management

Policies and programs to promote improved water management in irrigated agriculture include direct public incentive programs, such as cost-sharing and technical assistance for water-conserving practices, and various institutional reforms that increase producer incentives to adopt conserving practices.

Public Incentive Programs

In some cases, an improved practice may not be readily adopted at the farm level, although its use could result in substantial offsite economic and environmental benefits. Public investment in onfarm cost-sharing and technical assistance may be justified where market incentives alone are insufficient to achieve desired rates of technology adoption.

Onfarm Cost-Sharing. With the signing of the Federal Agricultural Improvement and Reform Act of 1996, USDA cost-sharing enters a new era. Under the new legislation, the Environmental Quality Incentives Program (EQIP) was established to provide technical and financial assistance to farmers and ranchers for improved irrigation management, as well as improvements in cropping and grazing systems; wildlife habitat; sediment control; and manure, nutrient, and pest management. EQIP replaces most previous USDA programs providing financial assistance for IWM, including the Agricultural Conservation Program, the Water Quality Incentives Program, the Colorado River Basin Salinity Control Program, and the Great Plains Conservation Program.

Under EQIP, cost-share and incentive payments are available for a range of eligible structural and management practices. Payments are based on a targeting process, subject to payment limitations by individual and practice. Funds are to be allocated based on several criteria, including (1) significance of the resource problem in the area, (2) environmental benefits per dollar expended, (3) State or local contributions toward treatment costs, and (4) the effectiveness in meeting water-quality standards or other environmental objectives under Federal or State law. EQIP was authorized at $130 million in fiscal year 1996 and $200 million annually for fiscal years 1997-2002, with half of the funding dedicated to livestock production practices.

Limited cost-sharing for water conservation measures is also provided through the Bureau of Reclamation, U.S. Department of Interior. Under provisions of the 1992 Central Valley Project Improvement Act (CVPIA; P.L. 102-575), the Bureau of Reclamation is authorized to provide cost-sharing to irrigators supplied by the federally financed Central Valley Project (CVP) in central California. The Bureau may fund up to 100 percent of the cost of water-conserving measures. In return, the Federal Government receives a proportionate share of water conserved—equal to its financial contribution—to be used to meet Federal obligations for restoration of fish and wildlife habitat in the Central Valley region.

State and local governments may also provide financial support for water conservation. Various States—including Arizona, Colorado, Kansas, Montana, Texas, Utah, and Washington—offer grants for water conserving practices. Kansas, for example, has recently initiated cost-sharing for irrigation improvements designed to slow the decline in groundwater reserves. Many States provide low-interest loans or tax credits specifically for water-conserving equipment.

Technical Assistance. Technical assistance for selection, design, and operation of improved irrigation technologies is available through various public agencies and institutions. The USDA Natural Resources Conservation Service (NRCS) provides technical assistance under its conservation operations program and the EQIP program through local conservation districts. The Bureau of Reclamation also provides technical assistance to western irrigators receiving Federal project water. At the State level, technical assistance is available through irrigation and farm management specialists associated with the Cooperative Extension Service and land-grant institutions. Private irrigation consultants, irrigation districts, and irrigation equipment dealers are also important sources of water management information.

FRIS reports that the most commonly used sources of water-management information are extension agents or university specialists, 44 percent of farms; neighboring farmers, 44 percent; irrigation equipment dealers, 37 percent; and irrigation specialists from NRCS and other Federal agencies, 26 percent. Media reports, water suppliers, private consultants, and other sources each serve less than 20 percent of farms (USDC, 1996). Larger farms tend to rely on multiple sources, with greater emphasis on private consultants, irrigation specialists from universities and government agencies, and irrigation equipment dealers. In general, most producers rely on more than one information source for guidance in irrigation decisions.

Water Policy Reform

Water policy adjustments at the State and Federal level have encouraged improved water management in irrigated agriculture. However, the type and magnitude of adjustments vary widely across States, and Federal reforms have generally not been comprehensive.

Water Pricing. Changes in Federal water prices involving higher rates, per unit-water charges, and block-rate pricing may help to induce adoption of water-conserving technologies. However, pricing reform alone is not likely to prompt the level of overall water conservation desired on federally financed projects. Moore and Dinar (1995) conclude that irrigators supplied by federal water projects in southern California view water as a quantity-rationed input; while price adjustments have distributional impacts, water use is not likely to be significantly affected by small price increases under the current institutional system. Studies have suggested that irrigation water in general has a low price elasticity of demand, implying that prices would have to increase significantly in order to conserve meaningful quantities of water (Moore and others, 1994; Negri and Brooks, 1990; Caswell and Zilberman, 1985). Substitution of groundwater supplies, where physically available and economically viable, may further limit the effect of public water-pricing policy on investment in conserving technologies. Water-pricing policies may be more effective when implemented in conjunction with other determinants of technology choice and crop production.

Water Transfers. Market provisions for the sale of water rights or temporary lease of water would encourage the conservation of agricultural water by providing farmers compensation for unused water entitlements. However, legal and institutional barriers at the Federal, State and local levels have restricted widespread development of operational markets for water. For most Federal water projects, changes in water deliveries are subject to administrative review, and water is generally not transferred beyond the project service area. Further, laws governing water use and transfer are vested with the individual State. In most States, irrigators do not retain rights to water conserved through improved irrigation efficiency. Thus, water “saved” is not available for transfer and is most often used on the farm for higher yields or irrigation expansion. Meanwhile, political concerns have focused on downstream impacts and secondary effects of reduced agricultural activity on local communities.

In recent years, barriers to water marketing have been reduced in some locations. Statutory changes at the State level have increasingly recognized both the need to transfer water to meet new demands, and rights to water “salvaged” through conservation. Recent reform of water transfer policies under the CVPIA may suggest a relaxing of constraints on transfers involving Federal water supplies.

Water Conservation Programs. The Federal Government requires development of irrigation conservation plans—specifying improved irrigation management systems and practices—under certain conditions. USDA conservation plans must be in place for farms with highly erodible soils to qualify for program funding. An approved plan is also required for farmers receiving cost-share and incentive payments under EQIP. In addition, access to publicly financed water supplies is increasingly tied to improved water management. Water districts receiving Federal water through the Bureau of Reclamation are required to develop water conservation plans, including explicit contractual language on goals, implementation measures, and timetables in some cases.

States are assuming an increasing role in irrigation water conservation, although legal authorities and program activities vary widely. Many States, mostly in the West, have established water conservation programs. States may require local water conservation plans, and several have established local management areas in critical water resource areas. State-level activities include conservation planning, water-use permitting with conservation provisions, program monitoring and evaluation, financial support for conservation practices, and technical assistance.

Water policy reform—involving water pricing, transfer provisions, and conservation programs—provides increased incentives for improved management of water supplies at the farm level. Meanwhile, opportunities for improved water management have expanded with advances in irrigation equipment and practices, lower cost of many technologies, and expanded information resources. As regional water-supply pressures intensify, agriculture will rely increasingly on improved water management to sustain productivity and increase the economic value of irrigation water.

Authors: Marcel Aillery, (202) 219-0427 [maillery@econ.ag.gov]; and Noel Gollehon, (202) 219-0413.

References

Allen, Richard G., Charles Burt, A.J. Clemmens, and L.S. Willardson (1996). "Water Conservation Definitions From a Hydologic Viewpoint," North American Water and Environment Congress, 1996 American Society of Civil Engineers.

Bernardo, Daniel J., and Norman K. Whittlesey (1989). *Factor Demand in Irrigated Agriculture Under Conditions of Restricted Water Supplies*, U.S. Dept. Agr., Econ. Res. Serv., TB-1765, July.

Caswell, Margriet F., and David Zilberman (1985). "The Choices of Irrigation Technologies in California," *American Journal of Agricultural Economics,* Vol. 67, No. 2, pp. 224-234, May.

Howe, C.W. (1985). "Economic, Legal, and Hydrologic Dimensions of Potential Interstate Water Markets," *American Journal of Agricultural Economics,* Vol. 67, No. 5, pp. 1226-1230.

Kim, C.S., Ronald Fleming, Richard M. Adams, Marshall English, and Carmen Sandretto (1994). "An Economic Analysis of Agricultural Practices Related to Water Quality: The Ontario (Oregon) Demonstration Project." U.S. Dept. Agr., Econ. Res. Serv., AGES94-18, June.

Magleby, R., R. Selley, and P. Zara (1995). "Effectiveness and Economic Efficiency of Efforts to Reduce Nitrate Loadings to Groundwater: A Mid-Nebraska Example."

Paper presented at Soil and Water Conservation Society meetings, DesMoines, IA, Aug. 6-9.

Magleby, R., J. Kasal, D. Walker, and R. Gum (1989). "Economics of Controlling Sediment from Irrigation: An Idaho Example." U.S. Dept. Agr., Econ. Res. Serv., AGES89-33, Sept.

Moore, Michael R. (1991). "The Bureau of Reclamation's New Mandate for Irrigation Water Conservation: Purposes and Policy Alternatives," *Water Resources Research*. Vol. 27, pp. 145-155, Feb.

Moore, Michael R., and Ariel Dinar (1995). "Water and Land as Quantity-Rationed Inputs in California Agriculture: Empirical Tests and Water Policy Implications," *Land Economics*, Vol. 71, pp. 445-61.

Moore, Michael R., Noel R. Gollehon, and Marc B. Carey (1994). "Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price," *American Journal of Agricultural Economics*, Vol. 76, No. 4, pp. 859-874, Nov.

National Research Council (1996). *Review of the Department of Interior's National Irrigation Water Quality Program: Planning and Remediation*. Water Science and Technology Board.

Negri, Donald H., and John J. Hanchar (1989). *Water Conservation Through Irrigation Technology*. U.S. Dept. Agr., Econ. Res. Serv., AIB-576, Nov.

Negri, Donald H., and Douglas H. Brooks (1990). "Determinants of Irrigation Technology Choice," *Western Journal of Agricultural Economics*, Vol. 15, No. 2, pp. 213-223, Dec.

Schaible, G.D., C.S. Kim, and N.K. Whittlesey (1991). "Water Conservation Potential from Irrigation Technology Transitions in the Pacific Northwest," *Western Journal of Agricultural Economics*, Vol. 16, pp. 194-206.

Schaible, G.D., N.R. Gollehon, M.S. Kramer, M.P. Aillery, and M.R. Moore (1995). *Economic Analysis of Selected Water Policy Options for the Pacific Northwest*. U.S. Dept. Agr., Econ. Res. Serv., AER-720, June.

Sojka, Bob, and Rick Lentz (1996). "Polyacrylamide for Furrow-Irrigation Erosion Control," *Irrigation Journal*, Vol. 46, No. 1, Jan./Feb.

U.S. Department of Agriculture, Soil Conservation Service (1994). *A Productive Nation in Harmony With A Quality Environment: Soil Conservation Service - Strategic Initiatives for the 1990's.*

U.S. Department of Agriculture, Natural Resources and Conservation Service (1992). National Irrigation Erosion Study.

U.S. Department of Commerce, Bureau of the Census (1994). *1994 Census of Agriculture*, Vol. 1, Parts 1-51.

U.S. Department of Commerce, Bureau of the Census (1996). *Farm and Ranch Irrigation Survey (1994)*. Vol. 3, Part 1 - Related Surveys of *1992 Census of Agriculture*, AC92-RS-1.

U.S. Department of Commerce, Bureau of the Census (1990). *Farm and Ranch Irrigation Survey (1988)*. Vol. 3, Part 1 - Related Surveys of *1987 Census of Agriculture*, AC87-RS-1.

U.S. Department of Commerce, Bureau of the Census (1986). *1984 Farm and Ranch Irrigation Survey*. Special Report Series, AG84-SR-1.

U.S. Department of Commerce, Bureau of the Census (1982). *1979 Farm and Ranch Irrigation Survey*. Vol. 5, Part 8 - Special Reports of *1978 Census of Agriculture*, AC78-SR-8.

Vaux, H.J., Jr. (1986). "Economic Factors Shaping Western Allocation," *American Journal of Agricultural Economics*, Vol. 68, pp. 1135-42.